AFRL-RX-WP-TR-2013-0165

Transverse Uniaxial Composite Thermal Properties Data Base of Thermally Conductive Graphite Fibers with and without Contiguous Grown Graphite Fins

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July 2013
Interim Report

Approved for public release; distribution unlimited.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
July 2013	Interim	01 July 2008- 30 June 2013

4. TITLE AND SUBTITLE
Transverse Uniaxial Composite Thermal Properties Data Base of Thermally Conductive Graphite Fibers with and without Contiguous Grown Graphite Fins

5a. CONTRACT NUMBER
IN-HOUSE

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62102F

6. AUTHOR(S)
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5d. PROJECT NUMBER
4347

5e. TASK NUMBER

5f. WORK UNIT NUMBER X0S7

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory
Materials and Manufacturing Directorate
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Air Force Materiel Command
United States Air Force

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/RXCC

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RX-WP-TR-2013-0165

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
PA Case Number: 88ABW-2013-3432; Clearance Date: 02 Aug 2013. Report contains color.

14. ABSTRACT ***(Maximum 200 words)***
Using the format of Mil Handbook 17, a complete data base of the results of in house experimental efforts to determine if the growth of graphite fins from thermally conductive, highly graphitic fibers could enhance the transverse thermal conductivity of uniaxial tow bundle laid up composites. These results designated as **W**ith **F**ins (WF) are tabulated alongside additional tables of the transverse thermal conductivity of uniaxial tow bundle laid up composites made from the same fibers without graphite fins grown from their surface. They represent baseline comparisons and are designated as **W**ith **O**ut graphite **F**ins (WOF). Appendixes detailing the specific fabrication of the, unique to this effort, experimental graphite fibers with fins grown contiguously from their surfaces and the, also unique to this effort, fabrication of uniaxial composites from those fibers are appended to illustrate the unique techniques used to fabricate the finned graphite fibers and Uniaxial composites. Additional appendixes depicting the data incorporated into the tables in graphical form are also included.

15. SUBJECT TERMS
Uniaxial Transverse Thermal Conductivity, Thermally Conductive, Highly Graphitic Fibers, Composites

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
a. REPORT	b. ABSTRACT	c. THIS PAGE			Roger Gerzeski
Unclassified	Unclassified	Unclassified	SAR	245	19b. TELEPHONE NUMBER *(Include Area Code)* (937) 904-4323

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1.0 EXECUTIVE SUMMARY

Using the format of Mil Handbook 17, a complete data base of the results of in house experimental efforts to determine if the growth of graphite fins from thermally conductive, highly graphitic fibers could enhance the transverse thermal conductivity of uniaxial tow bundle laid up composites. These results designated as **W**ith **F**ins (WF) are tabulated alongside additional tables of the transverse thermal conductivity of uniaxial tow bundle laid up composites made from the same fibers without graphite fins grown from their surface. They represent baseline comparisons and are designated as **W**ith **O**ut graphite **F**ins (WOF). Appendixes detailing the specific fabrication of the, unique to this effort, experimental graphite fibers with fins grown contiguously from their surfaces and the, also unique to this effort, fabrication of uniaxial composites from those fibers are appended to illustrate the unique techniques used to fabricate the finned graphite fibers and Uniaxial composites. Additional appendixes depicting the data incorporated into the tables in graphical form are also included.

2.0 DATA BASE

2.1 Fin Growth

Table 1, Fin Growth Lengths YSH50A 6K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: YSH50A 6K Tows
Material Run Number: R10

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

Jig Material:	Ceramic
Number of Troughs:	3
Plasma:	
Wattage (W):	1000
Pressure (Torr):	40
H_2 (sccm):	50
Oxidation:	
0_2 (sccm):	0.5
Time (min):	15
Growth:	
Methane (sccm):	10
Time (min):	16
Heater Stage Temperature (^oC):	
Median:	857
Range:	831-858
Specimen Temperature (^oC):	
Median	904
Range:	858-918

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	O5a	C3	O5b	Overall
Average Length (nm):	238.95	237.42	333.79	269.11
Standard Deviation (nm):	143.43	112.03	149.26	140.30
Maximum Length (nm):	656.20	583.70	698.70	698.70
Minimum Length (nm):	77.77	63.67	107.50	63.67
Range (nm):	578.43	520.03	591.20	635.03
Data Points:	61	96	75	232

Notes: See "Appendix A: Fin Growth" For Further Information

Table 2, Fin Growth Lengths M55JB 6K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: M55JB 6K Tows
Material Run Number: R5

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

Jig Material:	Ceramic
Number of Troughs:	5
Plasma:	
Wattage (W):	1000
Pressure (Torr):	40
H_2 (sccm):	50
Oxidation:	
O_2 (sccm):	0.5
Time (min):	15
Growth:	
Methane (sccm):	10
Time (min):	12
Heater Stage Temperature (^oC):	
Median:	833
Range:	827-842
Specimen Temperature (^oC):	
Median:	858
Range:	858-985

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	O5a	M5a	C5	M5b	O5b	O5	M5	Overall
Average Length (nm):	287.01	57.45	73.62	123.36	87.99	151.78	94.82	127.15
Standard Deviation (nm):	220.54	28.73	34.23	66.73	53.29	153.35	62.76	135.12
Maximum Length (nm):	988.80	191.40	191.20	305.70	306.50	988.80	305.70	988.80
Minimum Length (nm):	35.99	29.27	24.16	25.96	24.06	24.06	25.96	24.06
Range (nm):	952.81	162.13	167.04	279.74	282.44	964.74	279.74	964.74
Data Points:	62	55	66	72	58	-	-	313

Table 3, Fin Growth Lengths YSH60A 6K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: YSH60A 6K Tows
Material Run Number: R4

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

Jig Material:	Ceramic
Number of Troughs:	5 (Outer 3 on one side used)
Plasma:	
Wattage (W):	1000
Pressure (Torr):	40
H_2 (sccm):	50
Oxidation:	
O_2 (sccm):	0.5
Time (min):	5
Growth:	
Methane (sccm):	10
Time (min):	15
Heater Stage Temperature (^oC):	
Median:	867
Range:	-
Specimen Temperature (^oC):	
Median;	886
Range:	-

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	C5	M5b	O5b	Overall
Average Length (nm):	401.73	222.90	279.01	299.77
Standard Deviation (nm):	222.77	82.58	147.16	176.94
Maximum Length (nm):	798.10	586.50	789.80	798.10
Minimum Length (nm):	72.50	80.70	81.80	72.50
Range (nm):	725.60	505.80	708.00	725.60
Data Points:	95	98	81	274

Notes: See "Appendix A: Fin Growth" For Further Information

Table 4, Fin Growth Lengths YS80A 3K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: YS80A 3K Tows
Material Run Number: R2

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

- Jig Material: Ceramic
  - Number of Troughs: 3
- Plasma:
  - Wattage (W): 1000
  - Pressure (Torr): 40
  - H_2 (sccm): 50
  - Oxidation:
    - O_2 (sccm): 0.5
    - Time (min): 15
  - Growth:
    - Methane (sccm): 10
    - Time (min): 15.5
  - Heater Stage Temperature (^oC):
    - Median: 864
    - Range: 864-886
  - Specimen Temperature (^oC):
    - Median: 929
    - Range: 851-993

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	O3a	C3	O3b	Overall
Average Length (nm):	246.39	278.07	497.89	344.46
Standard Deviation (nm):	115.10	102.33	208.71	187.37
Maximum Length (nm):	674.50	477.00	1135.00	1135.00
Minimum Length (nm):	66.31	59.14	142.70	59.14
Range (nm):	608.19	417.86	992.30	1075.86
Data Points:	98	121	115	334

Table 5, Fin Growth Lengths P100S 2K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: P100S 2K Tows
Material Run Number: R1-3

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

Jig Material:	Ceramic
Number of Troughs:	7
Plasma:	
Wattage (W):	700
Pressure (Torr):	30
H_2 (sccm):	50
Oxidation:	
O_2 (sccm):	0.5
Time (min):	15
Growth:	
Methane (sccm):	10
Time (min):	15
Heater Stage Temperature (^oC):	
Median:	-
Range:	852-901
Specimen Temperature (^oC):	
Median:	-
Range:	830-900

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	O7	MO7a	CM7a	CM7b	MO7b	Overall
Average Length (nm):	147.64	148.28	77.87	99.24	87.69	113.68
Standard Deviation (nm):	96.31	57.59	36.35	52.30	53.54	66.52
Maximum Length (nm):	513.90	322.20	175.80	327.70	345.50	513.90
Minimum Length (nm):	33.12	66.28	16.80	36.48	37.38	16.80
Range (nm):	480.78	255.91	159.00	291.22	308.12	497.10
Data Points:	80	66	61	78	65	350

Table 6, Fin Growth Lengths P100S 2K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: P100S 2K Tows
Material Run Number: R13

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

Jig Material:	Ceramic
Number of Troughs:	5
Plasma:	
Wattage (W):	700
Pressure (Torr):	30
H_2 (sccm):	50
Oxidation:	
O_2 (sccm):	0.5
Time (min):	15
Growth:	
Methane (sccm):	10
Time (min):	16
Heater Stage Temperature (^oC):	
Median:	846
Range:	845-855
Specimen Temperature (^oC):	
Median:	826
Range:	853-1066

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	O5a	M5a	C5	M5b	O5b	Overall
Average Length (nm):	272.67	109.18	88.53	119.99	219.67	166.25
Standard Deviation (nm):	94.46	65.43	38.44	53.48	78.10	100.59
Maximum Length (nm):	546.70	570.60	239.90	298.90	437.30	570.60
Minimum Length (nm):	45.32	36.95	43.82	41.56	75.78	36.95
Range (nm):	501.38	533.65	196.08	257.34	361.52	533.65
Data Points:	73	81	45	64	62	325

Table 7, Fin Growth Lengths P100S 2K Tows Graphite Fiber

General Material Class: Graphite Fiber
Fiber Name: P100S 2K Tows
Material Run Number: R17

Tabulated By: Aaron Sprague
Tabulated On: June 2013
Checked By: Roger Gerzeski
Checked On: July 2013

Fin Growth Conditions:

- Jig Material: Ceramic
  - Number of Troughs: 5
- Plasma:
  - Wattage (W): 700
  - Pressure (Torr): 30
  - H_2 (sccm): 50
  - Oxidation:
    - O_2 (sccm): 0.5
    - Time (min): 15
  - Growth:
    - Methane (sccm): 10
    - Time (min): 16
  - Heater Stage Temperature (^oC):
    - Median: 846
    - Range: 843-849
  - Specimen Temperature (^oC):
    - Median: 826
    - Range: 842-934

Notes: See "Appendix A: Fin Growth" For Further Information

Fin Lengths:

Fiber Location:	O5a	M5a	C5	M5b	O5b	Overall
Average Length (nm):	357.38	117.92	137.80	98.26	128.99	157.22
Standard Deviation (nm):	211.12	52.96	75.01	58.83	71.96	133.11
Maximum Length (nm):	812.00	266.50	416.20	275.30	394.30	812.00
Minimum Length (nm):	109.50	32.28	26.50	37.10	41.20	26.50
Range (nm):	702.50	234.22	389.70	238.20	353.10	785.50
Data Points:	39	73	52	43	44	251

2.2 Section 2: Transverse Uniaxial Composite Properties

Table 8, Thermo-Physical Properties Of ER2 WF YSH50A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron **Sprague**
Fiber:	YSH50A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YSH50 ER2 WF	Checked On: July 2013

Preform:

Fiber:

Type:	YSH50A 6K Tows
Fin Status:	WF
Material Run:	ER2

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.2

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	53.4
Maximum:	59.3
Minimum:	44.5
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.6214
Maximum:	1.7046
Minimum:	1.4713
STD or CV:	0.0819
Data Points:	6
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	784
Initial Fiber Chains:	450
Final Fiber Chains:	188

Fiber Chain Ends:

Gap:	2061
Pocket:	340
Inner Edge:	152
Outer Edge:	97
Left Edge:	0
Right Edge:	0
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.5555	0.7200	0.6836	0.7294	0.7967	0.8669	0.9256	0.9787
Maximum:	0.6486	0.8369	0.7856	0.8338	0.9079	0.9769	1.0400	1.0990
Minimum:	0.4542	0.6400	0.6246	0.6787	0.7412	0.8117	0.8722	0.9251
STD or CV:	0.0738	0.0964	0.0762	0.0727	0.0777	0.0757	0.0780	0.0813
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.103	1.869	1.698	1.554	1.439	1.340	1.250	1.194
Maximum:	2.111	1.909	1.706	1.582	1.449	1.342	1.270	1.197
Minimum:	2.098	1.831	1.687	1.534	1.430	1.336	1.239	1.193
STD or CV:	0.007	0.039	0.010	0.025	0.010	0.003	0.017	0.002
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	1.888	2.181	1.882	1.837	1.885	1.885	1.880	1.899
Maximum:	2.327	2.725	2.284	2.248	2.261	2.236	2.255	2.247
Minimum:	1.502	1.723	1.550	1.530	1.588	1.597	1.595	1.626
STD or CV:	0.236	0.277	0.203	0.183	0.173	0.168	0.165	0.164
Data Points:	72	72	72	72	72	72	72	72
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 9, Thermo-Physical Properties Of ER2 FR1 WOF YSH50A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By:	Aaron Sprague
Fiber:	YSH50A	Tabulated On:	June 2013
Resin:	Epon 826 – Cure Agent W	Checked By:	Roger Gerzeski
Material Run Number:	YSH50 ER2 WOF FR1	Checked On:	July 2013

Preform:

Fiber:

Type:	YSH50A 6K Tows
Fin Status:	WOF FR1
Material Run:	ER2

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.2

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	66.0
Maximum:	71.8
Minimum:	61.3
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7353
Maximum:	1.9043
Minimum:	1.6221
STD or CV:	0.0943
Data Points:	7
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	758
Initial Fiber Chains:	379
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	456
Pocket:	30
Inner Edge:	89
Outer Edge:	0
Left Edge:	0
Right Edge:	0
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(°C): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125°C and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 °C/min

Temperature(°C):	-75	-50	-25	0	-	-	-	-
Average (J/g°C):	0.5749	0.7460	0.7192	0.7744	-	-	-	-
Maximum:	0.7453	0.9084	0.9837	0.9529	-	-	-	-
Minimum:	0.3912	0.5688	0.5268	0.5713	-	-	-	-
STD or CV:	0.1760	0.1692	0.1839	0.931	-	-	-	-
Data Points:	4	4	4	4	-	-	-	-
Batches:	1	1	1	1	-	-	-	-

Notes: See "Appendix D: Heat Capacity" For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	-	-	1.792	1.641	-	-	-	-
Maximum:	-	-	1.806	1.662	-	-	-	-
Minimum:	-	-	1.769	1.615	-	-	-	-
STD or CV:	-	-	0.020	0.024	-	-	-	-
Data Points:	-	-	3	3	-	-	-	-
Batches:	-	-	1	1	-	-	-	-

Notes: See "Appendix E: Diffusivity" For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	1.896	2.277	1.990	1.978	-	-	-	-
Maximum:	2.838	3.078	2.729	2.679	-	-	-	-
Minimum:	1.047	1.611	1.352	1.360	-	-	-	-
STD or CV:	0.540	0.462	0.455	0.443	-	-	-	-
Data Points:	84	84	84	84	-	-	-	-
Batches:	1	1	1	1	-	-	-	-

Notes: See "Appendix F: Conductivity" For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 10, Thermo-Physical Properties Of ER2 FR2 WOF YSH50A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By:	Aaron Sprague
Fiber:	YSH50A	Tabulated On:	June 2013
Resin:	Epon 826 – Cure Agent W	Checked By:	Roger Gerzeski
Material Run Number:	YSH50 ER2 WOF FR2	Checked On:	July 2013

Preform:

Fiber:

Type:	YSH50A 6K Tows
Fin Status:	WOF FR2
Material Run:	ER2

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.2

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	66.0
Maximum:	71.8
Minimum:	61.3
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7353
Maximum:	1.9043
Minimum:	1.6221
STD or CV:	0.0943
Data Points:	7
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	758
Initial Fiber Chains:	379
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	456
Pocket:	30
Inner Edge:	89
Outer Edge:	0
Left Edge:	0
Right Edge:	0
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	-	-	-	-
Average (J/g^oC):	0.5749	0.7460	0.7192	0.7744	-	-	-	-
Maximum:	0.7453	0.9084	0.9837	0.9529	-	-	-	-
Minimum:	0.3912	0.5688	0.5268	0.5713	-	-	-	-
STD or CV:	0.1760	0.1692	0.1839	0.931	-	-	-	-
Data Points:	4	4	4	4	-	-	-	-
Batches:	1	1	1	1	-	-	-	-

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	-	-	1.792	1.641	-	-	-	-
Maximum:	-	-	1.806	1.662	-	-	-	-
Minimum:	-	-	1.769	1.615	-	-	-	-
STD or CV:	-	-	0.020	0.024	-	-	-	-
Data Points:	-	-	3	3	-	-	-	-
Batches:	-	-	1	1	-	-	-	-

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	-	-	2.234	2.205	-	-	-	-
Maximum:	-	-	3.073	3.016	-	-	-	-
Minimum:	-	-	1.502	1.493	-	-	-	-
STD or CV:	-	-	0.512	0.493	-	-	-	-
Data Points:	-	-	84	84	-	-	-	-
Batches:	-	-	1	1	-	-	-	-

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 11, Thermo-Physical Properties Of ER3 WF YSH50A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YSH50A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YSH50 ER3 WF	Checked On: July 2013

Preform:

Fiber:

Type:	YSH50A 6K Tows
Fin Status:	WF
Material Run:	ER3

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.0

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	56.4
Maximum:	58.9
Minimum:	54.5
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.5849
Maximum:	1.6367
Minimum:	1.5006
STD or CV:	0.0736
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	853
Initial Fiber Chains:	586
Final Fiber Chains:	383

Fiber Chain Ends:

Gap:	3062
Pocket:	353
Inner Edge:	235
Outer Edge:	192
Left Edge:	6
Right Edge:	0
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.7982	0.9706	0.9549	1.0163	1.0998	1.1815	1.2583	1.3345
Maximum:	0.8282	1.0020	0.9852	1.0470	1.1310	1.2150	1.2930	1.3750
Minimum:	0.7179	0.8905	0.8709	0.9280	1.0090	1.0870	1.1600	1.2300
STD or CV:	0.0536	0.0536	0.0560	0.0588	0.0605	0.0630	0.0655	0.0698
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	1.798	1.683	1.493	1.359	1.270	1.185	1.125	1.037
Maximum:	1.810	1.693	1.499	1.371	1.279	1.188	1.131	1.042
Minimum:	1.790	1.670	1.481	1.350	1.258	1.180	1.122	1.030
STD or CV:	0.011	0.012	0.010	0.011	0.011	0.004	0.005	0.006
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	2.256	2.592	2.259	2.191	2.229	2.223	2.248	2.197
Maximum:	2.422	2.774	2.416	2.350	2.384	2.366	2.396	2.350
Minimum:	1.916	2.238	1.936	1.882	1.917	1.926	1.958	1.906
STD or CV:	0.160	0.161	0.146	0.140	0.139	0.135	0.134	0.132
Data Points:	36	36	36	36	36	36	36	36
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 12, Thermo-Physical Properties Of ER3 WOF YSH50A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YSH50A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YSH50 ER3 WOF	Checked On: July 2013

Preform:

Fiber:

Type:	YSH50A 6K Tows
Fin Status:	WOF
Material Run:	ER3

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.0

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	57.5
Maximum:	60.9
Minimum:	48.6
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7310
Maximum:	1.7429
Minimum:	1.7168
STD or CV:	0.0132
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	901
Initial Fiber Chains:	504
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	783
Pocket:	26
Inner Edge:	100
Outer Edge:	0
Left Edge:	5
Right Edge:	1
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	1.0924	1.2830	1.2270	1.2720	1.3470	1.4213	1.4910	1.5565
Maximum:	1.2220	1.4320	1.3550	1.3930	1.4680	1.5400	1.6100	1.6750
Minimum:	0.9606	1.1330	1.0970	1.1490	1.2250	1.3000	1.3720	1.4380
STD or CV:	0.1156	0.1379	0.1155	0.1093	0.1087	0.1076	0.1077	0.1079
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	1.574	1.431	1.313	1.222	1.135	1.070	1.007	0.949
Maximum:	1.588	1.440	1.319	1.228	1.140	1.075	1.015	0.956
Minimum:	1.561	1.424	1.305	1.215	1.131	1.063	0.999	0.939
STD or CV:	0.014	0.008	0.007	0.007	0.005	0.006	0.008	0.009
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	2.933	3.171	2.789	2.691	2.661	2.634	2.601	2.559
Maximum:	3.312	3.587	3.118	2.978	2.930	2.888	2.850	2.792
Minimum:	2.553	2.760	2.456	2.402	2.393	2.376	2.355	2.321
STD or CV:	0.272	0.299	0.232	0.204	0.188	0.176	0.167	0.158
Data Points:	36	36	36	36	36	36	36	36
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 13, Thermo-Physical Properties Of ER3 WF YS80A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YS80A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YS80 ER3 WF	Checked On: July 2013

Preform:

Fiber:

Type:	YS80A 3K Tows Surface Finish Removed (See Appendix B: Bulk Comp Fabrication)
Fin Status:	WF
Material Run:	ER3 Initial

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.0

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	53.1
Maximum:	62.0
Minimum:	47.8
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.8136
Maximum:	2.1875
Minimum:	1.6728
STD or CV:	0.2076
Data Points:	6
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	703
Initial Fiber Chains:	577
Final Fiber Chains:	181

Fiber Chain Ends:

Gap:	2553
Pocket:	200
Inner Edge:	209
Outer Edge:	72
Left Edge:	13
Right Edge:	6
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(°C): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125°C and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 °C/min

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (J/g°C):	0.4032	0.6329	0.5533	0.5976	0.6449	0.7132	0.7732	0.8313
Maximum:	0.4377	0.6589	0.5877	0.6327	0.6873	0.7514	0.8117	0.8672
Minimum:	0.3775	0.6159	0.5308	0.5767	0.6161	0.6784	0.7375	0.7958
STD or CV:	0.0258	0.0183	0.0253	0.0251	0.0326	0.0372	0.0399	0.0404
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	-	2.377	2.192	2.071	1.926	1.792	1.676	1.571
Maximum:	-	2.383	2.210	2.088	1.953	1.798	1.689	1.578
Minimum:	-	2.365	2.173	2.050	1.898	1.784	1.662	1.564
STD or CV:	-	0.010	0.019	0.019	0.028	0.007	0.014	0.007
Data Points:	-	3	3	3	3	3	3	3
Batches:	-	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	-	2.733	2.199	2.240	2.282	2.321	2.356	2.372
Maximum:	-	3.455	2.841	2.886	2.972	2.961	3.005	2.999
Minimum:	-	2.430	1.928	1.979	1.986	2.027	2.059	2.084
STD or CV:	-	0.296	0.248	0.251	0.261	0.266	0.270	0.269
Data Points:	-	72	72	72	72	72	72	72
Batches:	-	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 14, Thermo-Physical Properties Of ReRun ER3 WF YS80A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By:	Aaron Sprague
Fiber:	YS80A	Tabulated On:	June 2013
Resin:	Epon 826 – Cure Agent W	Checked By:	Roger Gerzeski
Material Run Number:	YS80 ER3 WF Rerun	Checked On:	July 2013

Preform:

Fiber:

Type:	YS80A 3K Tows Surface Finish Removed (See Appendix B: Bulk Comp Fabrication)
Fin Status:	WF
Material Run:	ER3 Rerun

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.0

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	53.1
Maximum:	62.0
Minimum:	47.8
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.8136
Maximum:	2.1875
Minimum:	1.6728
STD or CV:	0.2076
Data Points:	6
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	703
Initial Fiber Chains:	577
Final Fiber Chains:	181

Fiber Chain Ends:

Gap:	2553
Pocket:	200
Inner Edge:	209
Outer Edge:	72
Left Edge:	13
Right Edge:	6
TBE:	0

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 168hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.7091	0.8201	0.9725	1.1156	1.2520	1.3765	1.4968	1.5988
Maximum:	0.7955	0.9231	1.1070	1.2790	1.4350	1.5800	1.7210	1.8380
Minimum:	0.5807	0.6861	0.8224	0.9524	1.0770	1.1910	1.3010	1.3970
STD or CV:	0.0982	0.1049	0.1221	0.1384	0.1518	0.1650	0.1781	0.1874
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	-	2.377	2.192	2.071	1.926	1.792	1.676	1.571
Maximum:	-	2.383	2.210	2.088	1.953	1.798	1.689	1.578
Minimum:	-	2.365	2.173	2.050	1.898	1.784	1.662	1.564
STD or CV:	-	0.010	0.019	0.019	0.028	0.007	0.014	0.007
Data Points:	-	3	3	3	3	3	3	3
Batches:	-	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	-	3.531	3.857	4.183	4.428	4.479	4.564	4.514
Maximum:	-	4.812	5.356	5.819	6.212	6.226	6.376	6.353
Minimum:	-	2.719	2.975	3.268	3.464	3.558	3.634	3.659
STD or CV:	-	0.543	0.589	0.633	0.665	0.666	0.677	0.636
Data Points:	-	72	72	72	72	72	72	72
Batches:	-	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 15, Thermo-Physical Properties Of ER3 WOF YS80A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YS80A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YS80 ER3 WOF	Checked On: July 2013

Preform:

Fiber:

Type:	YS80A 3K Tows Surface Finish Removed (See Appendix B: Bulk Comp Fabrication)
Fin Status:	WOF
Material Run:	ER3 Initial

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.0

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	65.3
Maximum:	71.9
Minimum:	57.4
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.780.
Maximum:	1.8876
Minimum:	1.6951
STD or CV:	0.0657
Data Points:	6
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	1073
Initial Fiber Chains:	546
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	730
Pocket:	15
Inner Edge:	110
Outer Edge:	0
Left Edge:	1
Right Edge:	0
TBE:	6

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.7570	0.9283	0.8479	0.8752	0.9468	1.0336	1.1245	1.2029
Maximum:	0.9358	1.1410	1.0450	1.0770	1.1350	1.2030	1.2740	1.3420
Minimum:	0.5616	0.6021	0.5744	0.6086	0.6818	0.7567	0.8641	0.9077
STD or CV:	0.1796	0.2415	0.2108	0.2123	0.2048	0.1871	0.1821	0.1989
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.462	2.074	1.823	1.675	1.553	1.438	1.328	1.245
Maximum:	2.584	2.081	1.831	1.691	1.559	1.451	1.344	1.258
Minimum:	2.348	2.062	1.815	1.661	1.543	1.429	1.312	1.236
STD or CV:	0.118	0.010	0.008	0.015	0.009	0.012	0.016	0.011
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	3.267	3.437	2.753	2.606	2.618	2.649	2.664	2.663
Maximum:	4.360	4.524	3.612	3.430	3.338	3.295	3.232	3.190
Minimum:	2.245	2.106	1.773	1.707	1.788	1.911	1.928	1.902
STD or CV:	0.694	0.790	0.604	0.560	0.502	0.426	0.387	0.394
Data Points:	72	72	72	72	72	72	72	72
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 16, Thermo-Physical Properties Of ReRun ER3 WOF YS80A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YS80A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YS80 ER3 WOF Rerun	Checked On: July 2013

Preform:

Fiber:

Type:	YS80A 3K Tows Surface Finish Removed (See Appendix B: Bulk Comp Fabrication)
Fin Status:	WOF
Material Run:	ER3 Rerun

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.0

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	65.3
Maximum:	71.9
Minimum:	57.4
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.780.
Maximum:	1.8876
Minimum:	1.6951
STD or CV:	0.0657
Data Points:	6
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	1073
Initial Fiber Chains:	546
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	730
Pocket:	15
Inner Edge:	110
Outer Edge:	0
Left Edge:	1
Right Edge:	0
TBE:	6

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 168hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.7127	0.7777	0.8583	0.9294	1.0020	1.0597	1.1047	1.1383
Maximum:	0.7289	0.7954	0.8768	0.9487	1.0220	1.0800	1.1250	1.1600
Minimum:	0.6806	0.7441	0.8230	0.8923	0.9631	1.0200	1.0640	1.0960
STD or CV:	0.0278	0.0291	0.0306	0.0321	0.0337	0.0344	0.0352	0.0367
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.462	2.074	1.823	1.675	1.553	1.438	1.328	1.245
Maximum:	2.584	2.081	1.831	1.691	1.559	1.451	1.344	1.258
Minimum:	2.348	2.062	1.815	1.661	1.543	1.429	1.312	1.236
STD or CV:	0.118	0.010	0.008	0.015	0.009	0.012	0.016	0.011
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	3.123	2.867	2.785	2.764	2.770	2.714	2.614	2.525
Maximum:	3.553	3.128	3.023	3.017	3.006	2.959	2.854	2.756
Minimum:	2.709	2.599	2.539	2.506	2.522	2.472	2.369	2.297
STD or CV:	0.191	0.133	0.125	0.124	0.122	0.119	0.115	0.111
Data Points:	54	54	54	54	54	54	54	54
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 17, Thermo-Physical Properties Of BR1 WOF YS80A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YS80A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YS80 BR1 WOF	Checked On: July 2013

Preform:

Fiber:

Type:	YS80A 3K Tows Surface Finish Removed (See Appendix B: Bulk Comp Fabrication)
Fin Status:	WOF
Material Run:	BR1 Initial

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	25.4

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 130 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	54.1
Maximum:	65.5
Minimum:	40.2
Data Points:	5
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7832
Maximum:	1.8221
Minimum:	1.7280
STD or CV:	0.0491
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	694
Initial Fiber Chains:	256
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	311
Pocket:	9
Inner Edge:	47
Outer Edge:	0
Left Edge:	1
Right Edge:	0
TBE:	2

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	1.356	1.669	1.488	1.498	1.575	1.649	1.713	
Maximum:	1.835	2.219	1.935	1.920	1.956	2.016	2.067	2.087
Minimum:	1.07	1.252	1.171	1.220	1.314	1.398	1.477	1.590
STD or CV:	0.365	0.443	0.341	0.308	0.290	0.280	0.270	0.235
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.418	2.085	1.867	1.729	1.587	1.494	1.395	1.306
Maximum:	2.441	2.123	1.872	1.742	1.594	1.499	1.403	1.311
Minimum:	2.383	2.055	1.859	1.716	1.582	1.490	1.387	1.301
STD or CV:	0.031	0.0335	0.007	0.013	0.006	0.005	0.008	0.005
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	5.820	6.217	4.953	4.616	4.475	4.393	4.264	4.132
Maximum:	8.121	8.615	6.599	6.094	5.702	5.507	5.282	4.972
Minimum:	4.136	4.449	3.762	3.618	3.605	3.602	3.546	3.579
STD or CV:	1.383	1.460	1.004	0.842	0.726	0.664	0.595	0.479
Data Points:	36	36	36	36	36	36	36	36
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 18, Thermo-Physical Properties Of ReRun BR1 WOF YS80A / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	YS80A	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	YS80 BR1 WOF Rerun	Checked On: July 2013

Preform:

Fiber:

Type:	YS80A 3K Tows Surface Finish Removed (See Appendix B: Bulk Comp Fabrication)
Fin Status:	WOF
Material Run:	BR1 Rerun

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	25.4

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 130 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	54.1
Maximum:	65.5
Minimum:	40.2
Data Points:	5
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7832
Maximum:	1.8221
Minimum:	1.7280
STD or CV:	0.0491
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	694
Initial Fiber Chains:	256
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	311
Pocket:	9
Inner Edge:	47
Outer Edge:	0
Left Edge:	1
Right Edge:	0
TBE:	2

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 168hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.5273	0.6630	0.8303	0.9890	1.1378	1.2693	1.3930	1.4923
Maximum:	0.6742	0.7912	0.9450	1.0840	1.2170	1.3320	1.4570	1.5780
Minimum:	0.4547	0.5895	0.7525	0.9038	1.0440	1.1630	1.2720	1.3620
STD or CV:	0.1013	0.0890	0.0817	0.0738	0.0715	0.0749	0.0836	0.0920
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.418	2.085	1.867	1.729	1.587	1.494	1.395	1.306
Maximum:	2.441	2.123	1.872	1.742	1.594	1.499	1.403	1.311
Minimum:	2.383	2.055	1.859	1.716	1.582	1.490	1.387	1.301
STD or CV:	0.031	0.0335	0.007	0.013	0.006	0.005	0.008	0.005
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	2.272	2.460	2.767	3.050	3.252	3.385	3.477	3.481
Maximum:	2.998	3.051	3.225	3.443	3.567	3.640	3.743	3.773
Minimum:	1.872	2.091	2.422	2.682	2.872	2.997	3.060	3.071
STD or CV:	0.388	0.298	0.247	0.212	0.193	0.192	0.199	0.204
Data Points:	36	36	36	36	36	36	36	36
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 19, Thermo-Physical Properties Of ER2 WF P100S / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	P100S	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	P100 ER2 WF	Checked On: July 2013

Preform:

Fiber:

Type:	P100S 2K Tows
Fin Status:	WF
Material Run:	ER2

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.2

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	56.0
Maximum:	58.6
Minimum:	53.4
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.8054
Maximum:	1.8180
Minimum:	1.7955
STD or CV:	0.0115
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	823
Initial Fiber Chains:	540
Final Fiber Chains:	380

Fiber Chain Ends:

Gap:	1030
Pocket:	166
Inner Edge:	155
Outer Edge:	97
Left Edge:	4
Right Edge:	5
TBE:	148

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.9993	1.1778	1.1410	1.1973	1.2795	1.3598	1.4300	1.4958
Maximum:	1.0460	1.2350	1.1560	1.2450	1.3300	1.4120	1.4830	1.5480
Minimum:	0.9565	1.1270	1.1000	1.1570	1.2370	1.3160	1..860	1.4510
STD or CV:	0.0435	0.0534	0.0421	0.0410	0.0432	0.0446	0.0443	0.0440
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.429	2.165	1.984	1.804	1.662	1.598	1.461	1.316
Maximum:	2.455	2.207	2.019	1.831	1.679	1.620	1.481	1.334
Minimum:	2.414	2.107	1.952	1.776	1.631	1.578	1.437	1.303
STD or CV:	0.022	0.052	0.034	0.028	0.027	0.021	0.022	0.016
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	4.383	4.603	4.089	3.902	3.869	3.924	3.777	3.556
Maximum:	4.668	4.953	4.366	4.147	4.088	4.159	3.996	3.757
Minimum:	4.146	4.265	3.856	3.691	3.652	3.730	3.579	3.400
STD or CV:	0.172	0.205	0.146	0.129	0.126	0.123	0.115	0.100
Data Points:	36	36	36	36	36	36	36	36
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 20, Thermo-Physical Properties Of ER2 WOF P100S / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	P100S	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	P100 ER2 WOF	Checked On: July 2013

Preform:

Fiber:

Type:	P100S 2K Tows
Fin Status:	WOF
Material Run:	ER2

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	26.2

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	60.1
Maximum:	65.8
Minimum:	47.9
Data Points:	12
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7884
Maximum:	1.8082
Minimum:	1.7728
STD or CV:	0.0181
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	770
Initial Fiber Chains:	425
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	419
Pocket:	21
Inner Edge:	43
Outer Edge:	0
Left Edge:	1
Right Edge:	0
TBE:	18

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(°C): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125°C and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 °C/min

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (J/g°C):	0.9839	1.1630	1.1270	1.1843	1.2695	1.3530	1.4263	1.4933
Maximum:	0.9941	1.1790	1.1400	1.1960	1.2800	1.3650	1.4340	1.4990
Minimum:	0.9787	1.1530	1.1200	1.1760	1.2610	1.3440	1.4170	1.4850
STD or CV:	0.0069	0.0125	0.0089	0.0084	0.0081	0.0092	0.0077	0.0069
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.130	2.161	2.082	1.875	1.724	1.591	1.490	1.373
Maximum:	2.176	2.215	2.121	1.888	1.739	1.626	1.500	1.375
Minimum:	2.106	2.110	2.045	1.853	1.711	1.570	1.478	1.371
STD or CV:	0.040	0.053	0.038	0.019	0.014	0.031	0.011	0.002
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(°C):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	3.742	4.496	4.197	3.972	3.939	3.851	3.805	3.670
Maximum:	3.911	4.726	4.372	4.085	4.049	4.015	3.894	3.734
Minimum:	3.641	4.314	4.061	3.862	3.854	3.742	3.716	3.611
STD or CV:	0.074	0.108	0.078	0.054	0.047	0.073	0.044	0.035
Data Points:	36	36	36	36	36	36	36	36
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 21, Thermo-Physical Properties Of ER4 WF P100S / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	P100S	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	P100 ER4 WF	Checked On: July 2013

Preform:

Fiber:

Type:	P100S 2K Tows
Fin Status:	WF
Material Run:	ER4

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	25.7

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	58.5
Maximum:	63.5
Minimum:	48.5
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.7710
Maximum:	1.7864
Minimum:	1.7456
STD or CV:	0.0159
Data Points:	5
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	805
Initial Fiber Chains:	595
Final Fiber Chains:	387

Fiber Chain Ends:

Gap:	1581
Pocket:	196
Inner Edge:	145
Outer Edge:	113
Left Edge:	1
Right Edge:	11
TBE:	160

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.9224	1.1363	1.0553	1.0983	1.1725	1.2423	1.3065	1.3663
Maximum:	0.9759	1.2050	1.1020	1.1280	1.2130	1.2780	1.3390	1.3940
Minimum:	0.8500	1.0480	0.9882	1.0530	1.1120	1.1860	1.2520	1.3140
STD or CV:	0.0591	0.0764	0.0508	0.0358	0.0442	0.0405	0.0385	0.0360
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.605	2.193	1.965	1.805	1.667	1.531	1.470	1.317
Maximum:	2.661	2.220	1.969	1.811	1.682	1.542	1.647	1.325
Minimum:	2.555	2.170	1.960	1.797	1.658	1.523	1.365	1.311
STD or CV:	0.053	0.025	0.005	0.007	0.013	0.010	0.154	0.007
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	4.246	4.415	3.673	3.511	3.483	3.369	3.408	3.192
Maximum:	4.627	4.782	3.876	3.649	3.652	3.521	3.948	3.302
Minimum:	3.782	3.972	3.381	3.303	3.149	3.154	2.986	3.013
STD or CV:	0.250	0.265	0.157	0.105	0.114	0.101	0.310	0.079
Data Points:	60	60	60	60	60	60	60	60
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

Table 22, Thermo-Physical Properties Of ER4 WOF P100S / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	P100S	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	P100 ER4 WOF	Checked On: July 2013

Preform:

Fiber:

Type:	P100S 2K Tows
Fin Status:	WOF
Material Run:	ER4

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	25.7

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 175 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	60.1
Maximum:	64.4
Minimum:	54.6
Data Points:	9
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.8072
Maximum:	1.8565
Minimum:	1.7570
STD or CV:	0.0325
Data Points:	6
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	829
Initial Fiber Chains:	284
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	412
Pocket:	13
Inner Edge:	54
Outer Edge:	0
Left Edge:	2
Right Edge:	0
TBE:	10

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.7401	0.9078	0.8846	0.9440	1.0238	1.0970	1.1695	1.2398
Maximum:	0.7688	0.9376	0.9144	0.9742	1.0630	1.1160	1.1900	1.2630
Minimum:	0.6917	0.8433	0.8207	0.8873	0.9623	1.0410	1.1180	1.1960
STD or CV:	0.0340	0.0438	0.0438	0.0398	0.0434	0.0373	0.0345	0.0299
Data Points:	4	4	4	4	4	4	4	4
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.416	2.114	1.913	1.741	1.585	1.470	1.370	1.265
Maximum:	2.438	2.147	1.947	1.745	1.586	1.476	1.385	1.272
Minimum:	2.393	2.085	1.879	1.734	1.584	1.459	1.362	1.255
STD or CV:	0.032	0.031	0.034	0.006	0.001	0.009	0.013	0.009
Data Points:	2	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	3.244	3.482	3.059	2.971	2.948	2.915	2.901	2.840
Maximum:	3.512	3.742	3.310	3.164	3.112	3.061	3.070	2.987
Minimum:	2.901	3.112	2.709	2.701	2.700	2.669	2.679	2.646
STD or CV:	0.150	0.160	0.149	0.121	0.110	0.100	0.092	0.077
Data Points:	48	72	72	72	72	72	72	72
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate average

Table 23, Thermo-Physical Properties Of BR1 WOF P100S / Epon 826 – Cure Agent W Uniaxial Composite

General Material Class:	Graphite Fiber - Epoxy Composite	Tabulated By: Aaron Sprague
Fiber:	P100S	Tabulated On: June 2013
Resin:	Epon 826 – Cure Agent W	Checked By: Roger Gerzeski
Material Run Number:	P100 BR1 WOF	Checked On: July 2013

Preform:

Fiber:

Type:	P100S 2K Tows
Fin Status:	WOF
Material Run:	BR1

Resin:

Type:	Epon 826 – Cure Agent W
Curing Agent Content (PPH):	25.4

Forming:

Technique:	Tow Lay Up In An Aluminum Tool Then Vacuum Bagged Autoclave Cure
Lay Up Sequence Profile:	Hand Tow Lay Up See "Appendix B: Bulk Composite Fabrication"
Cure Profile:	Vacuum to -29 inch Pressurization Ramp Rate of 6 psi/min to 130 psi Heating Ramp Rate of 5°F/min to 250°F Hold at 250°F for 60 min Heating Ramp Rate of 5°F/min to 350°F Hold at 350°F for 120 min Cool Temperature to Room Temperature At 100°F Vent Pressure to Atmosphere At 100°F Vent Vacuum to Atmosphere
Post Cure Profile:	None.
Tooling Used:	Aluminum Trough See "Appendix B: Bulk Composite Fabrication"

General Property Type:

Fiber Volume:

Average (%):	55.1
Maximum:	61.7
Minimum:	44.9
Data Points:	8
Batches:	1
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Void Volume:

Average (%):	0
Test Method:	Optical Microscopy
Notes:	See Appendix C: Optical Microscopy For Micrographs

Density:

Average(gms/cm^3):	1.8027
Maximum:	1.8048
Minimum:	1.7996
STD or CV:	0.0027
Data Points:	3
Batches:	1
Test Method:	Archimedes Method

Fiber Chains:

Total Fibers Across:	775
Initial Fiber Chains:	371
Final Fiber Chains:	0

Fiber Chain Ends:

Gap:	505
Pocket:	13
Inner Edge:	84
Outer Edge:	0
Left Edge:	1
Right Edge:	0
TBE:	24

Specific Property Values:

Tested In Condition:

Atmosphere: N_2

Temperature(^oC): -90 - 130

Specimen PreConditioning Time-Duration: 24hrs at 125^oC and -29inch Vacuum

Heat Capacity:

Test Method: Conventional MCDS Heating Rate 2 ^oC/min

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (J/g^oC):	0.8321	1.0249	0.9844	1.0367	1.1152	1.1944	1.2672	1.3340
Maximum:	0.8901	1.0940	1.0410	1.0920	1.1720	1.2520	1.3250	1.3940
Minimum:	0.7816	0.9663	0.9356	0.9903	1.0680	1.1460	1.2190	1.2890
STD or CV:	0.0396	0.0484	0.0384	0.0369	0.0378	0.0383	0.0383	0.0386
Data Points:	5	5	5	5	5	5	5	5
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix D: Heat Capacity” For Graphical Heat Capacity Curves

Thermal Diffusivity:

Test Method: ASTM E1461

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (mm^2/s):	2.737	1.985	1.802	1.607	1.475	1.386	1.272	1.189
Maximum:	2.759	2.009	1.811	1.617	1.497	1.391	1.280	1.211
Minimum:	2.714	1.969	1.788	1.600	1.453	1.377	1.259	1.157
STD or CV:	0.023	0.021	0.013	0.009	0.022	0.008	0.011	0.028
Data Points:	3	3	3	3	3	3	3	3
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix E: Diffusivity” For Graphical Diffusivity Data Point Curves

Thermal Conductivity:

Test Method: Data Acquired By Calculating Every Permutation of Density X Diffusivity X Heat Capacity

Tested Orientation: Transverse

Temperature(^oC):	-75	-50	-25	0	25	50	75	100
Average (W/mK):	4.090	3.665	3.199	3.005	2.992	2.986	2.910	2.863
Maximum:	4.432	3.968	3.403	3.189	3.194	3.145	3.066	3.050
Minimum:	3.774	3.420	3.010	2.854	2.817	2.840	2.770	2.691
STD or CV:	0.183	0.160	0.114	0.098	0.098	0.088	0.082	0.093
Data Points:	45	45	45	45	45	45	45	45
Batches:	1	1	1	1	1	1	1	1

Notes: See “Appendix F: Conductivity” For Graphical Conductivity Data Points & Error Bars

Note: Temperatures listed are approximate averages

3.0 APPENDIX A: FIN GROWTH

3.1 Section 1: Microwave Plasma Chemical Vapor Deposition System

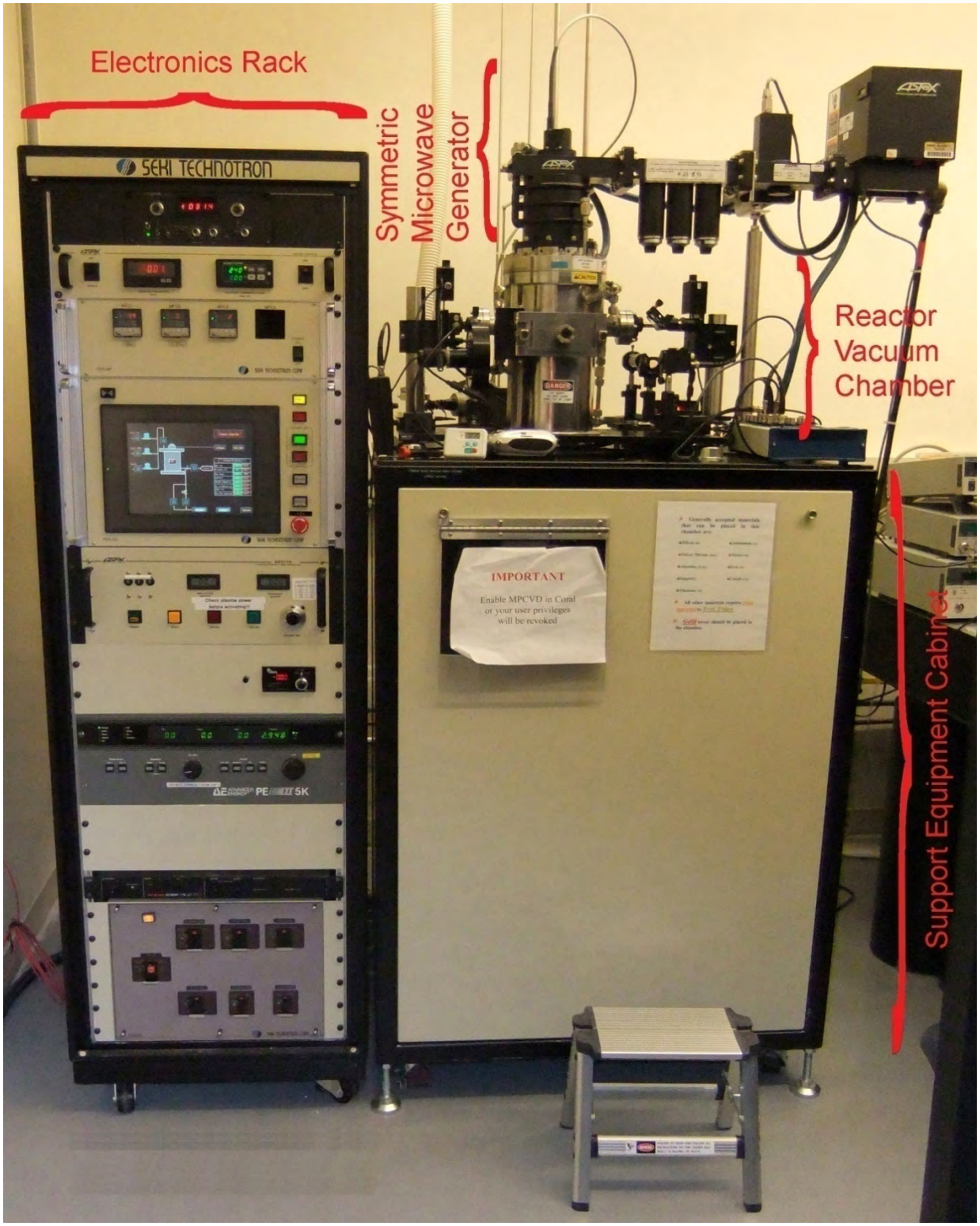


Figure FG1, SEKI TECHNOTRON Microwave Plasma Chemical Vapor Deposition System

RXBT-INTERNAL REPORT -2011

SEKI TECHNOTRON
Microwave Plasma Chemical Vapor Deposition (MWCVD)
Restricted Users Operations Manual

Roger Gerzeski
Thermal Sciences And Materials Branch (AFRL/RXBT)
Nonmetallic Materials Division
Materials And Manufacturing Directorate
WPAFB Ohio

May 2011
Internal Technical Report

RXBT Internal Technical Report.

AIR FORCE RESEARCH LABORATORY
MATERIALS AND MANUFACTURING DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

RXBT Internal Technical Report.

Figure FG2, MWPCVD System Operations Manual

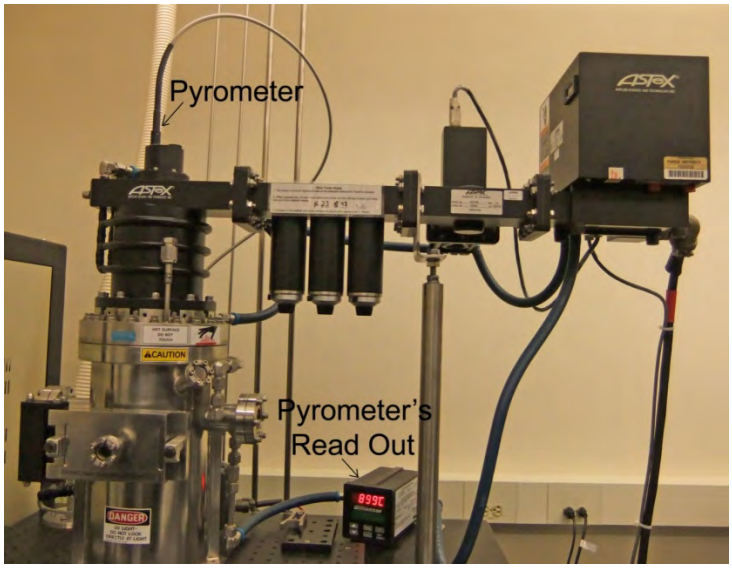


Figure FG3, Optical Pyrometer Location And Read Out

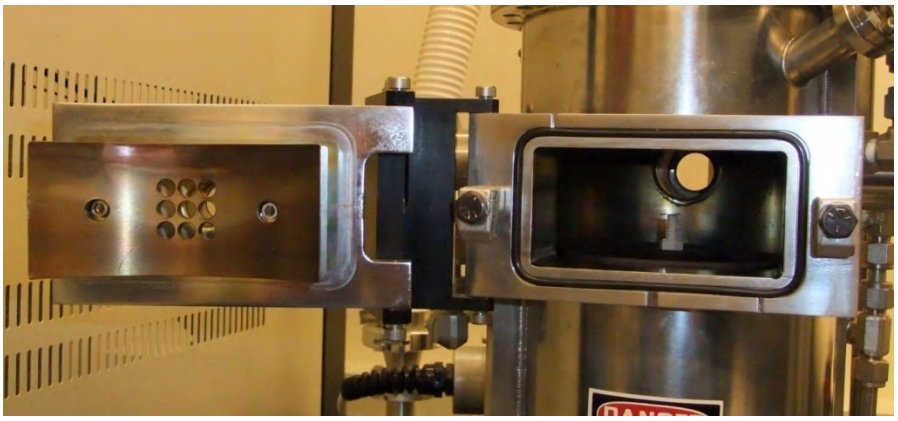


Figure FG4, Opened Reactor Chamber Door

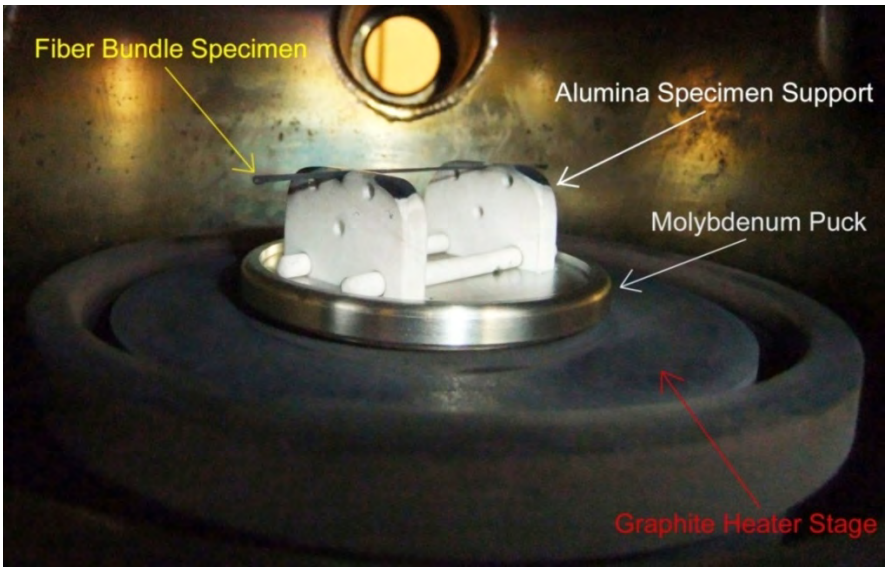
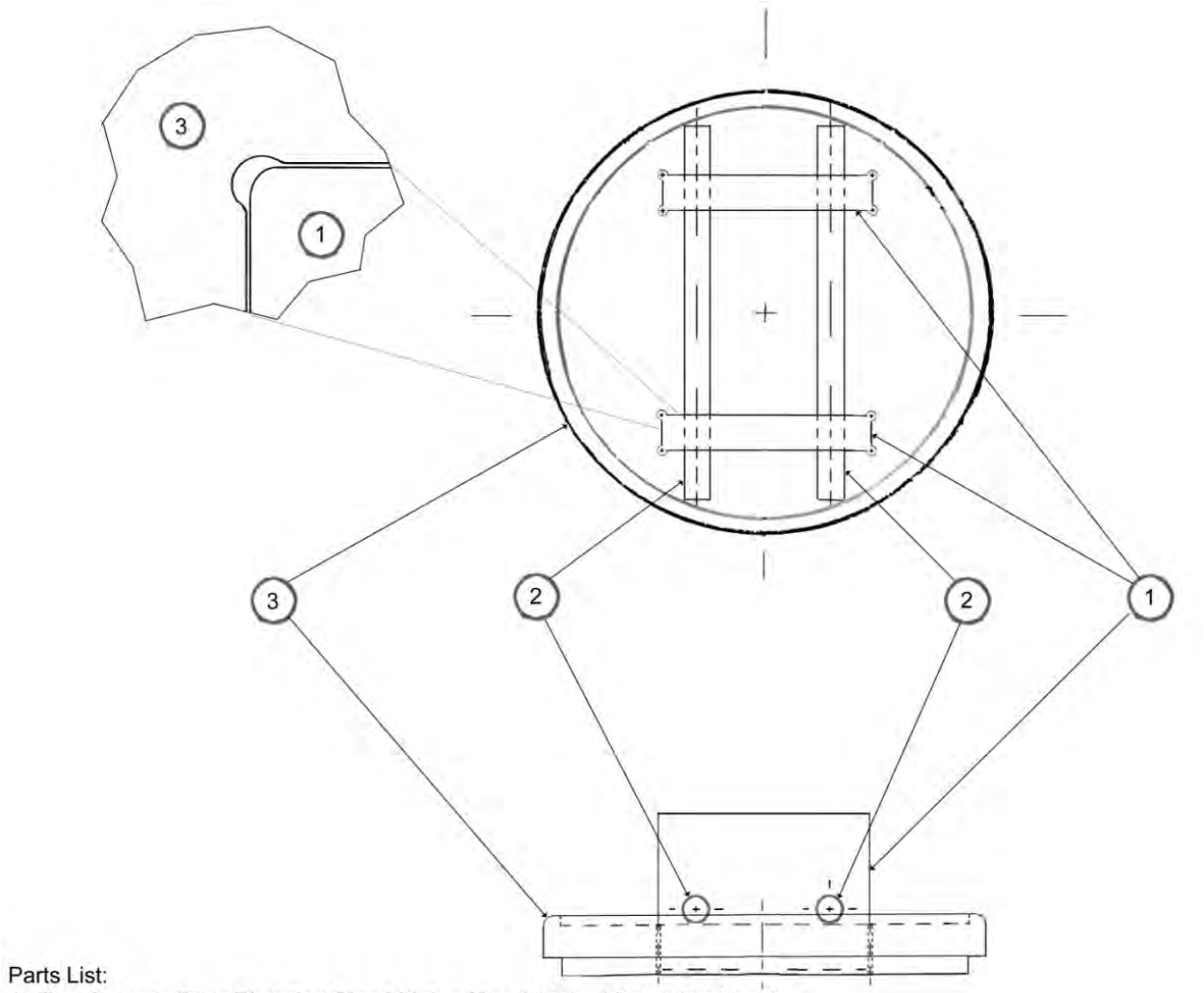


Figure FG5, Heater Stage, Inserted Molybdenum Puck, Ceramic Stand and Specimen

3.2 Section 2: Fiber Elevation Stand Overall Assembly



Parts List:
1. Two Ceramic Fiber Elevation Stand Plates (See Attached Detail Draftings)
2. Two 1.875" +/- 0.050" Long 0.125" OD Precision Ground (+/-0.001")
   Very High Temperature Nonporous High Alumina Rods
   McMaster-Carr Part Number 8446K11
3. One Slotted Molybdenum Puck (See Attached Detail Draftings)

Fiber Specimen Elevation Jig Assembly
Engineer: Roger Gerzeski
Date: Rev B 1 Apr 2010, Org 7 Feb 2010

Figure FG6, Fiber Elevation Stand Assembly Design

3.3 Section 3: Molybdenum Puck

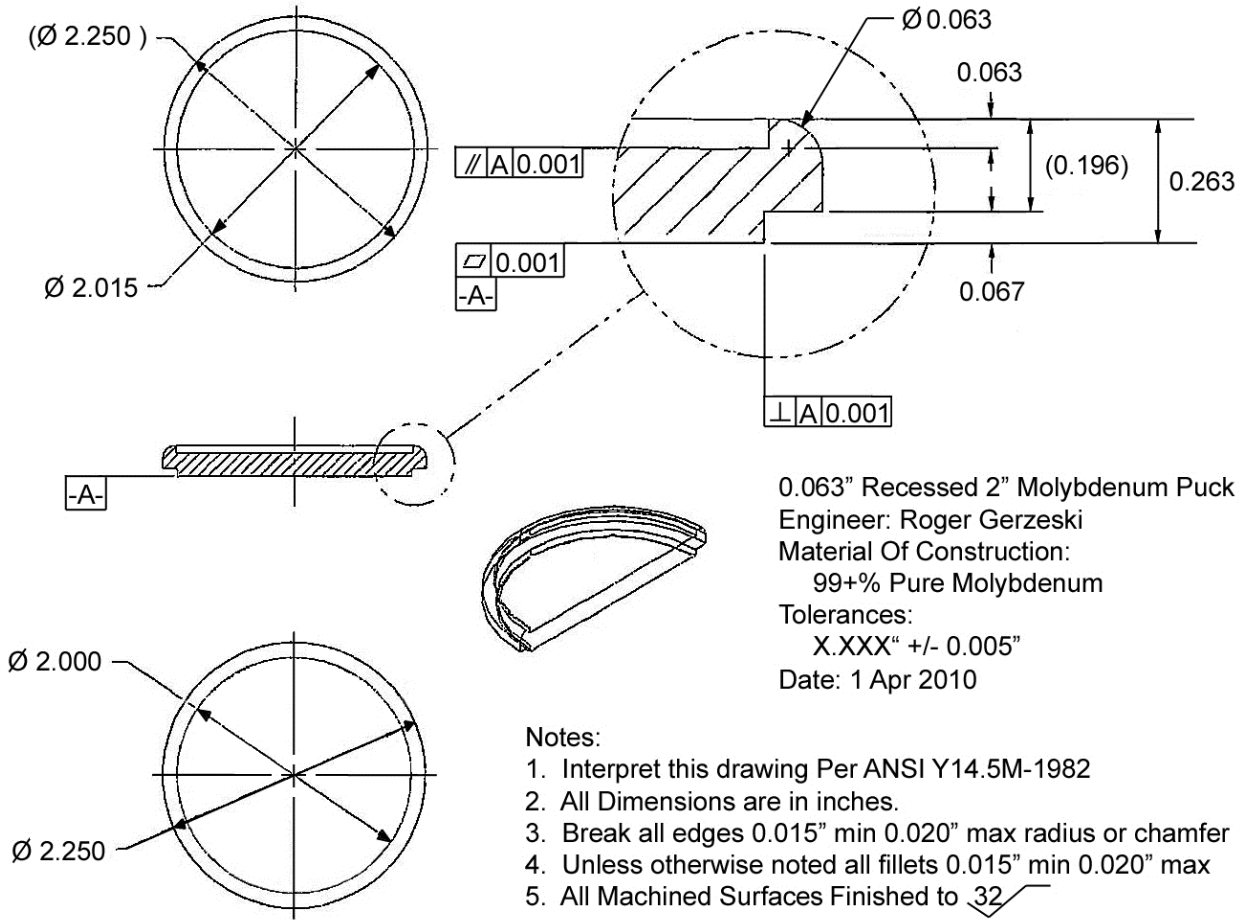


Figure FG7, Molybdenum Puck Design

Figure FG8, Molybdenum Puck

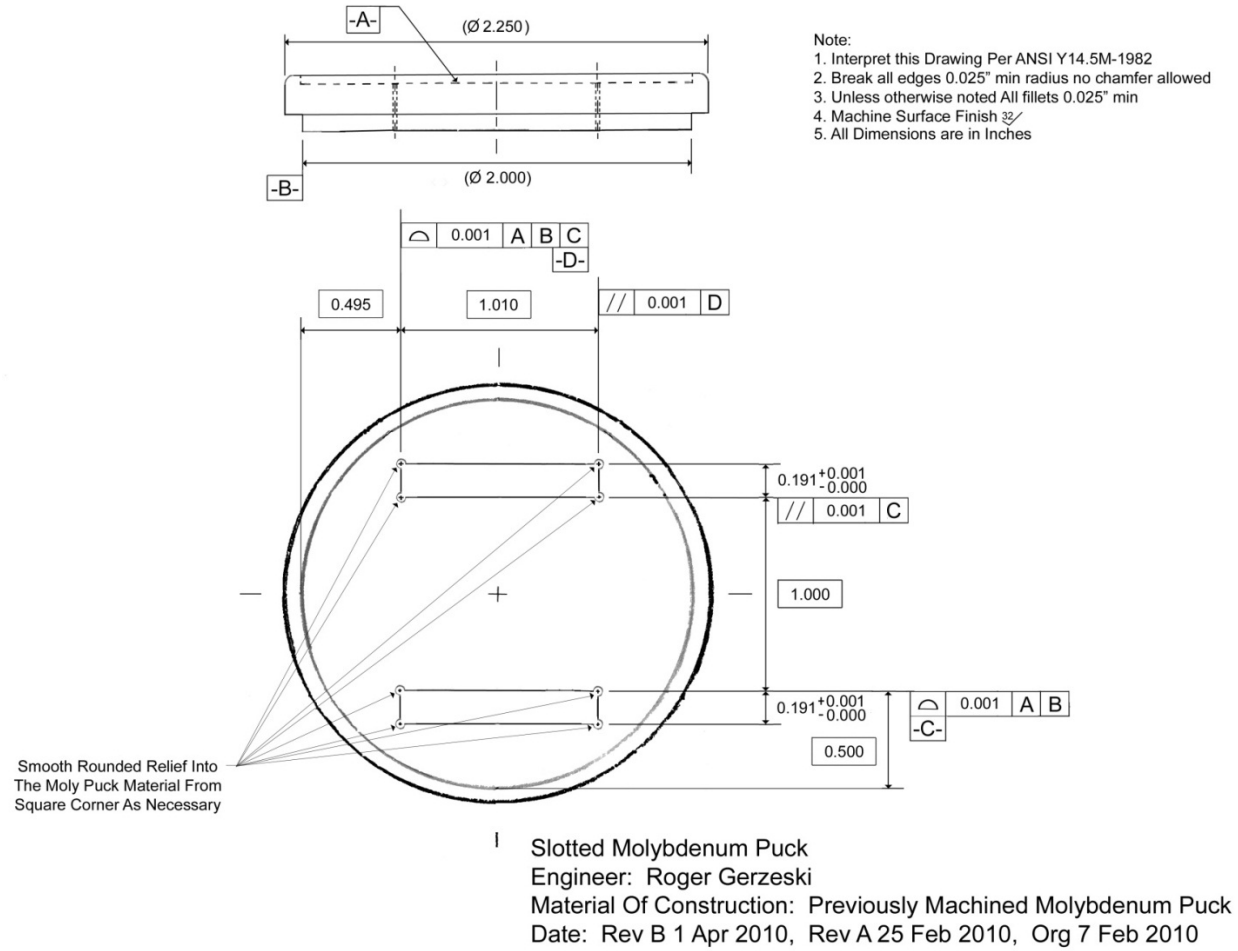


Figure FG9, Slotted Molybdenum Puck Design

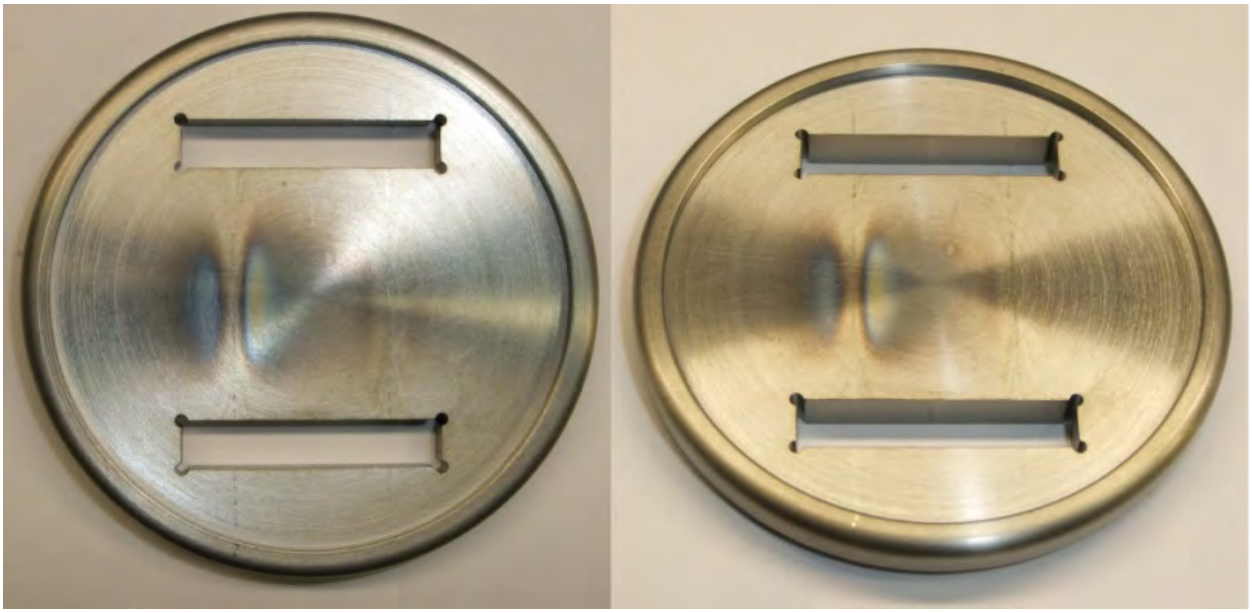


Figure FG10, Slotted Molybdenum Puck

3.4 Section 4: Ceramic Stands

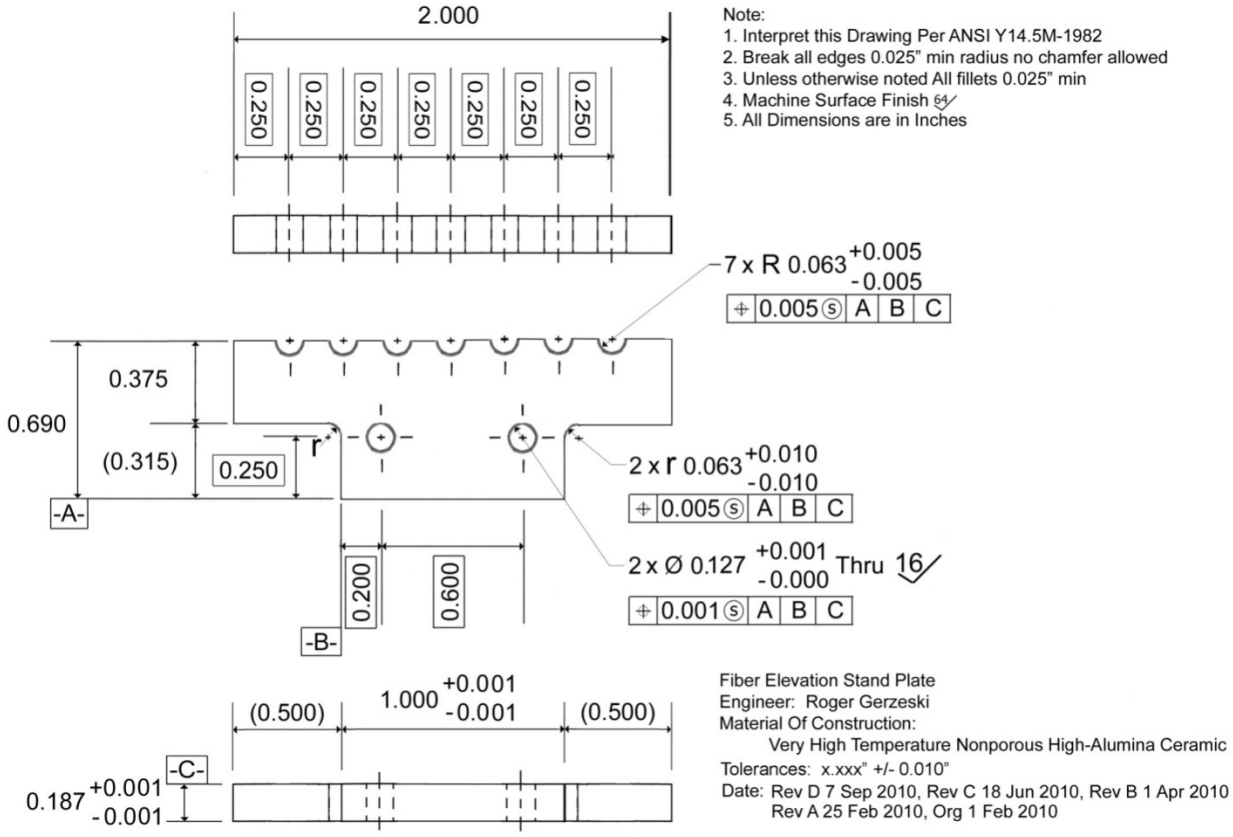


Figure FG11, Ceramic Specimen Elevation Seven One Quarter Inch Spaced Eighth Inch Slot T Stands

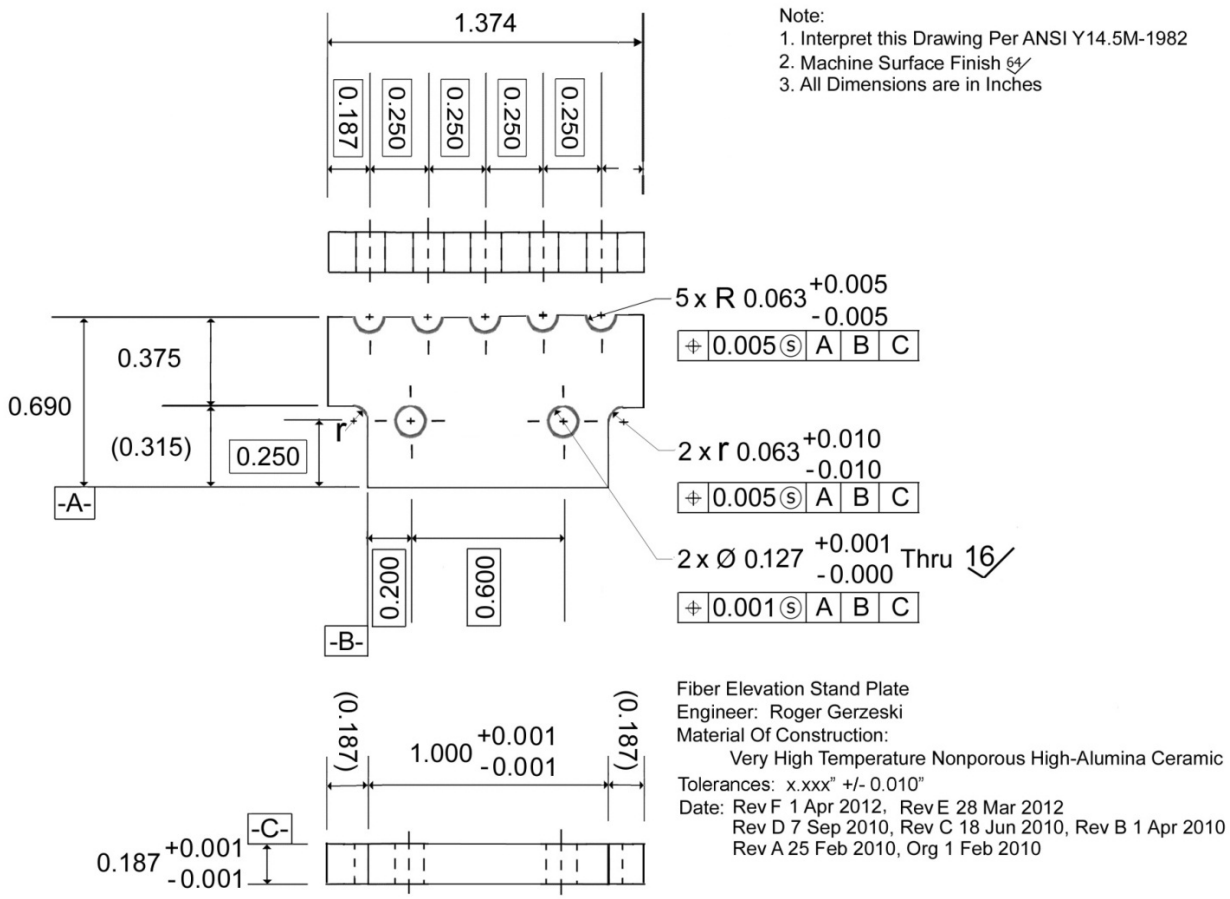


Figure FG12, Ceramic Specimen Elevation Five One Quarter Inch Spaced Eighth Inch Slot T Stands

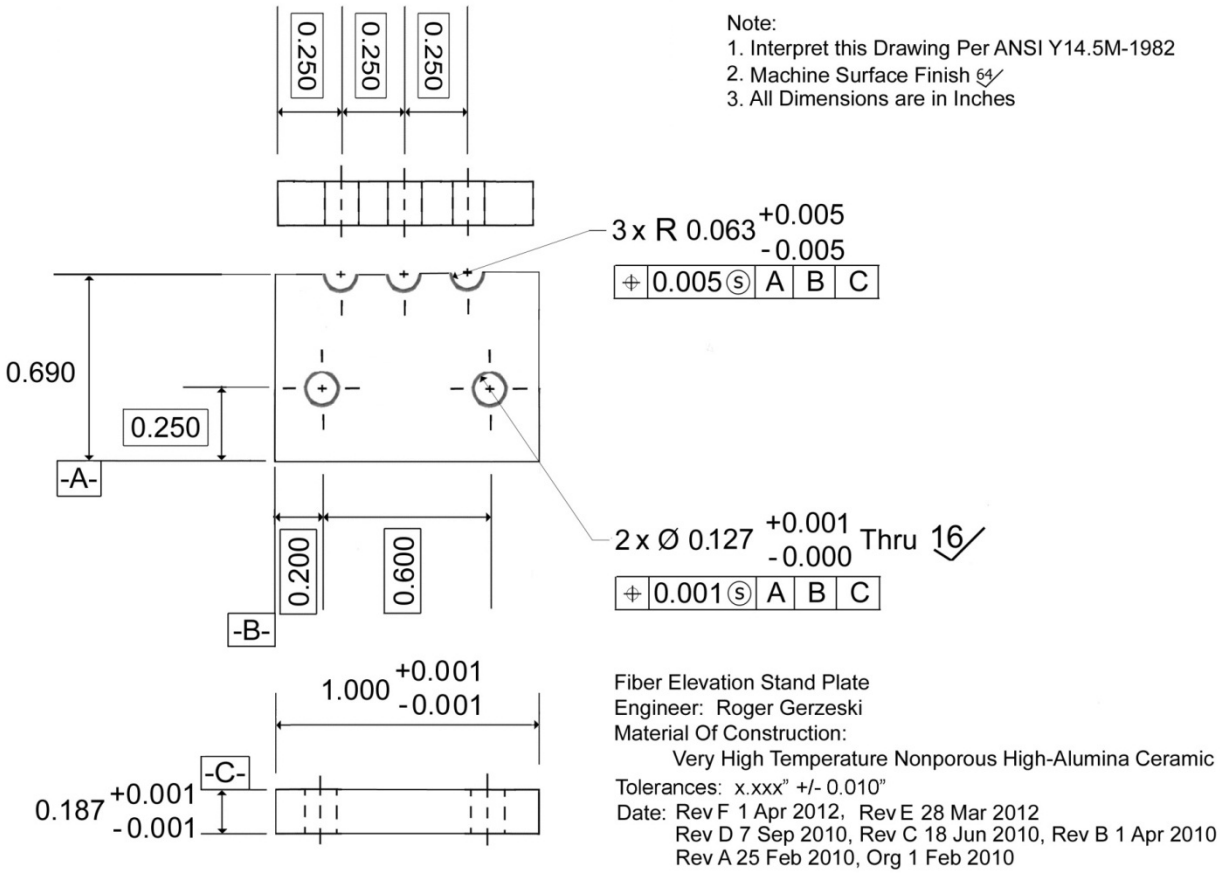


Figure FG13, Ceramic Specimen Elevation Three One Quarter Inch Spaced Eighth Inch Slot T Stands

3.5 Section 5: Ceramic Caps

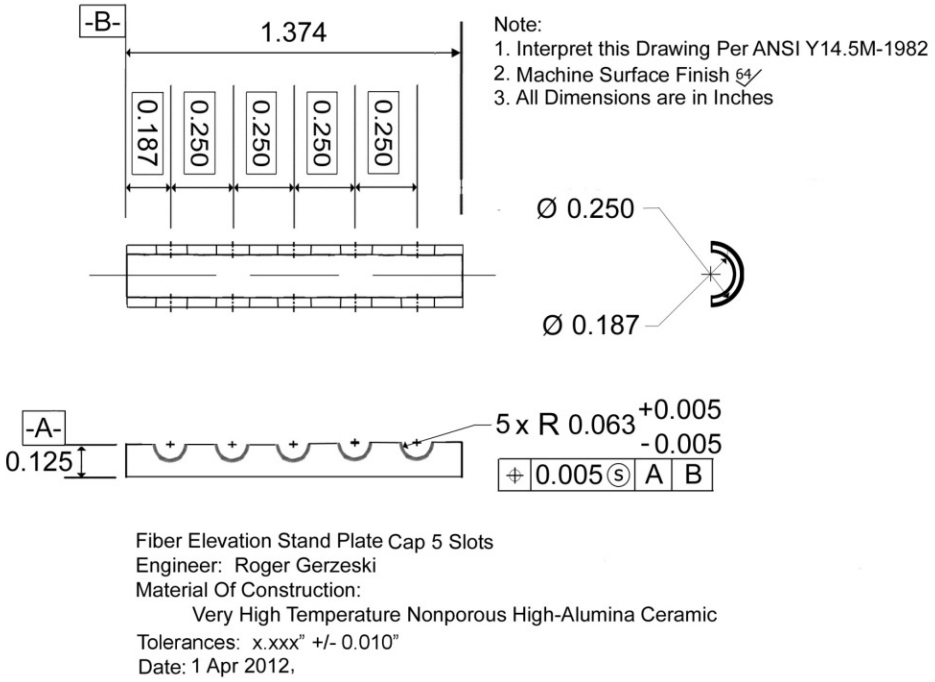


Figure FG14, Ceramic Five Specimen One Quarter Inch Spaced Eighth Inch Slot Cap

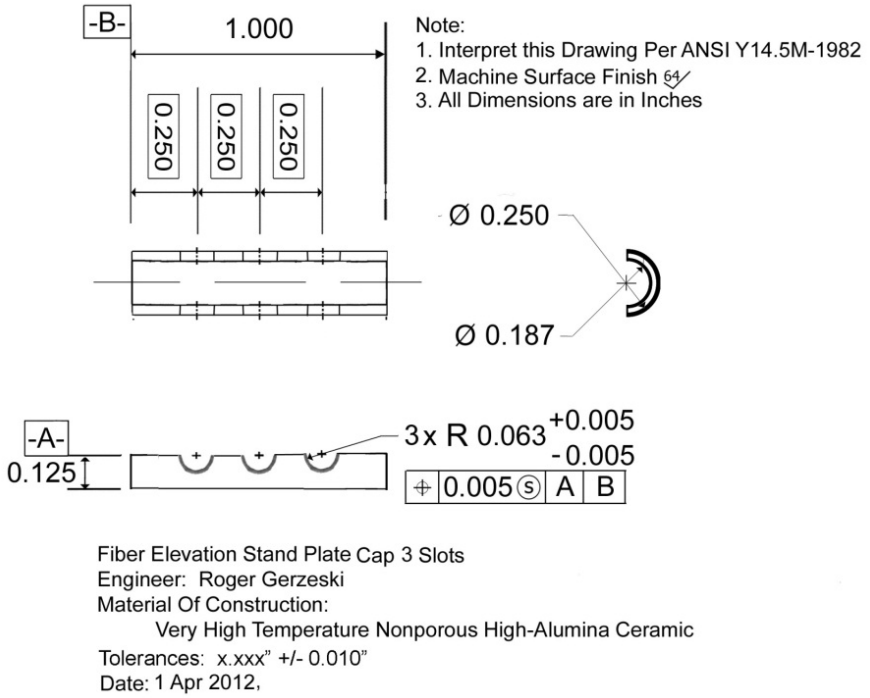


Figure FG15, Ceramic Three Specimen One Quarter Inch Spaced Eighth Inch Slot Cap

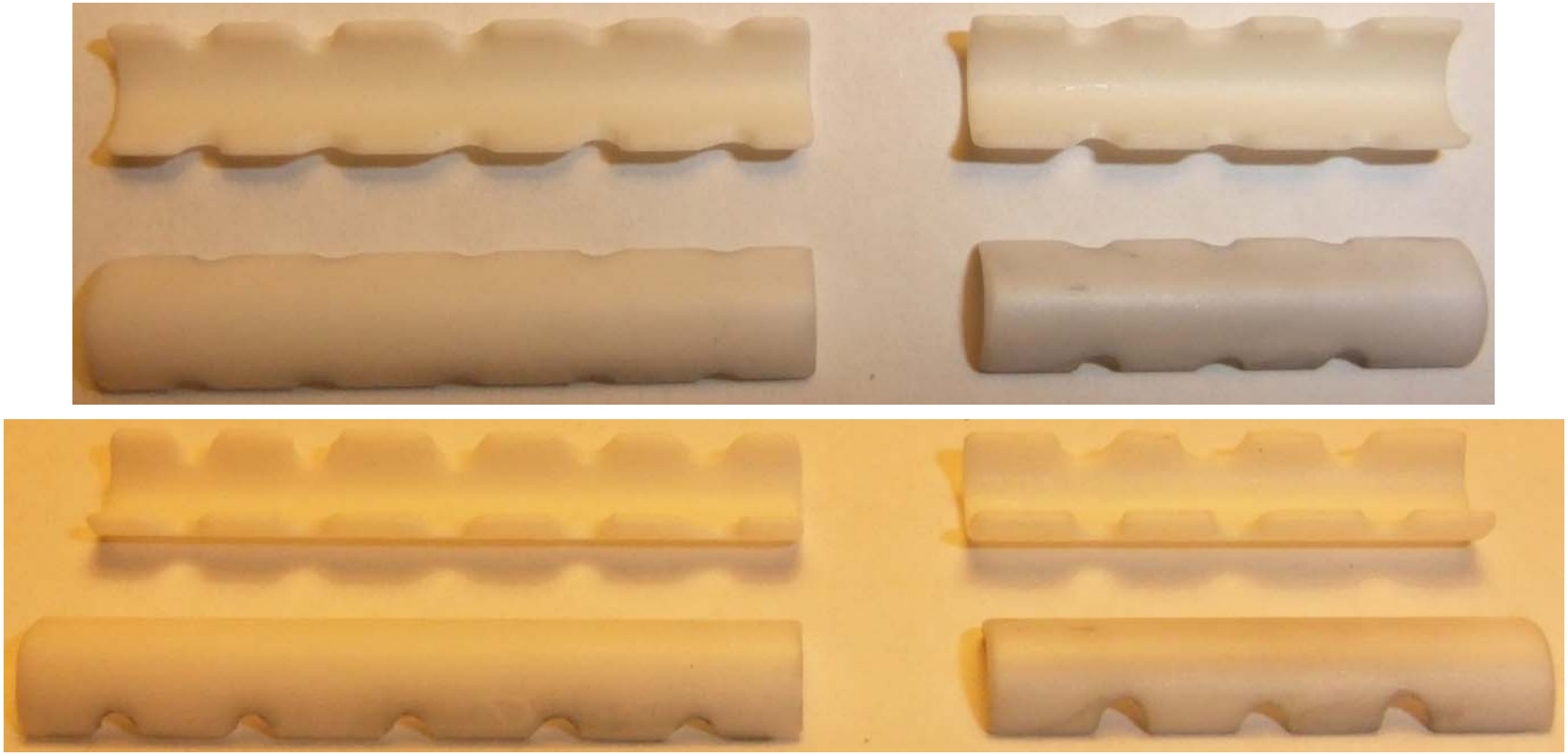
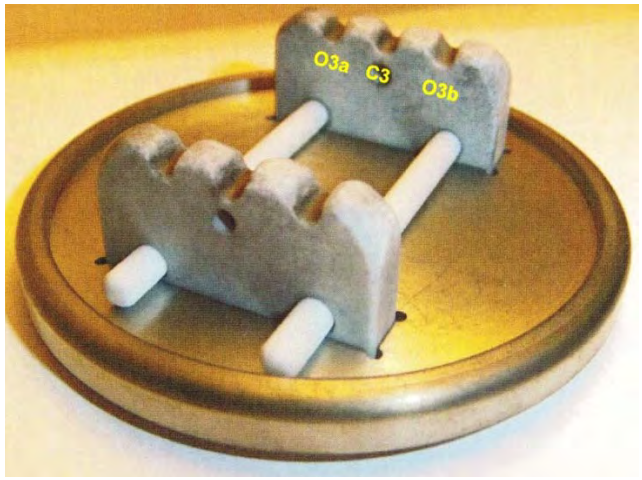


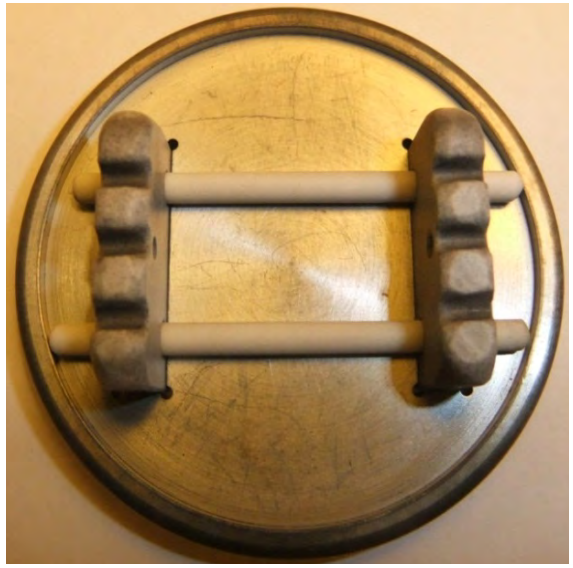
Figure FG16, Ceramic Caps

3.6 Section 6: Assembled Ceramic Jigs & Puck

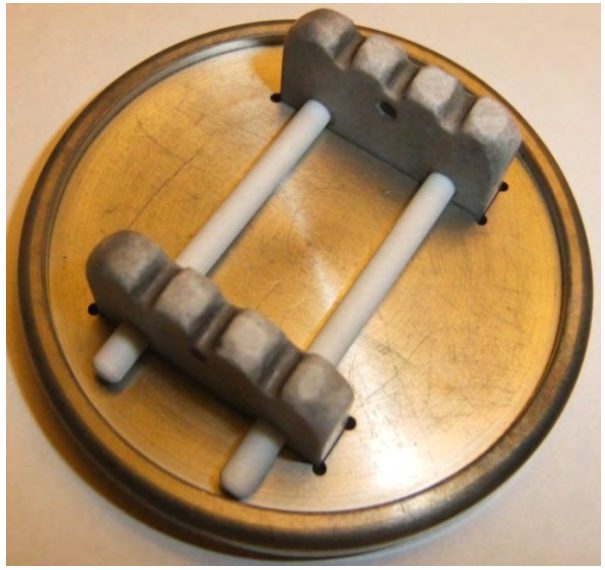


Labeled Slots View

End View



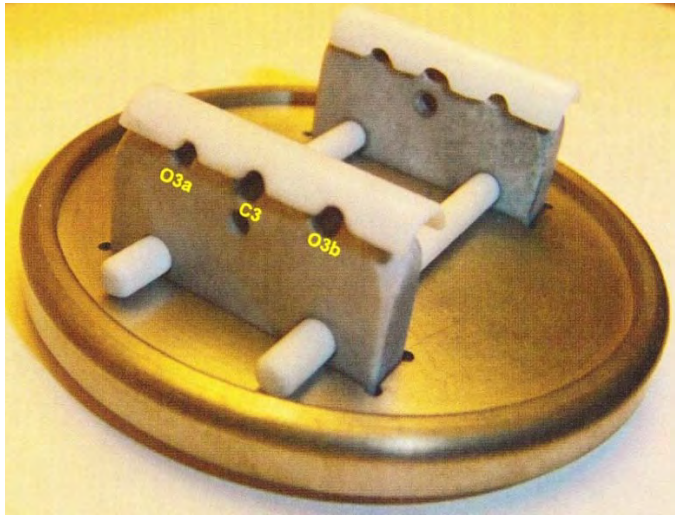
Top View I



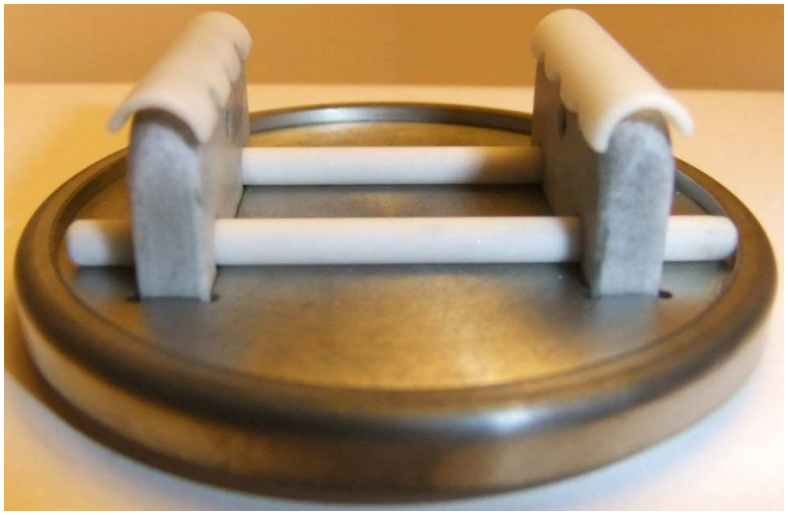
Top View II

Figure FG17, Un Capped Ceramic Specimen Elevation Three One Quarter Inch Spaced Eighth Inch Slot T Stands

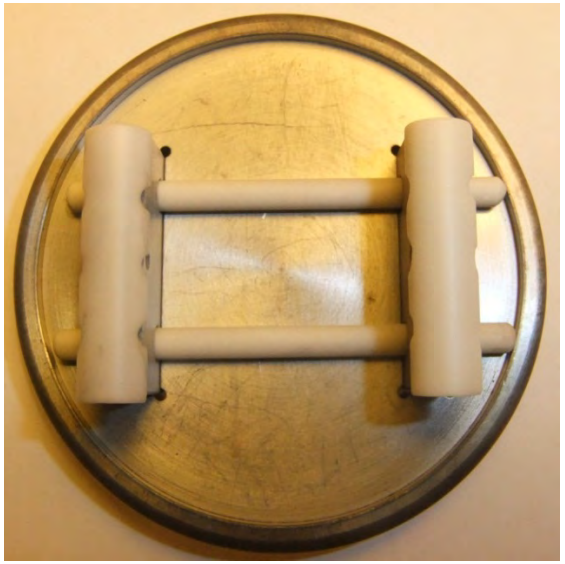
52



Labeled Slots View



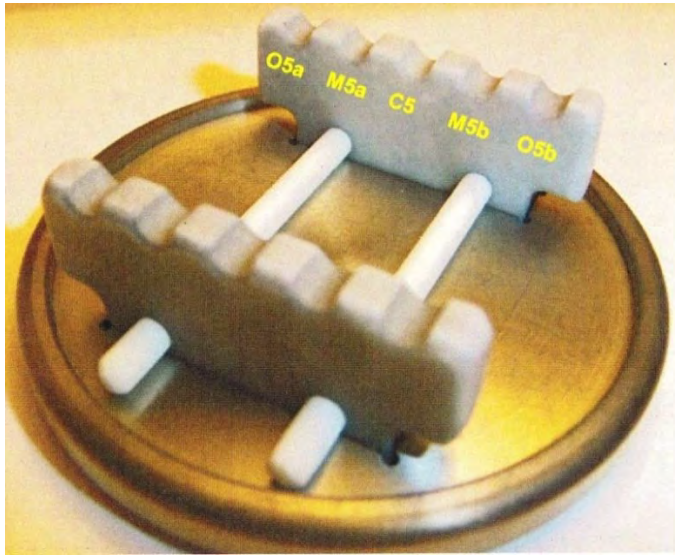
End View



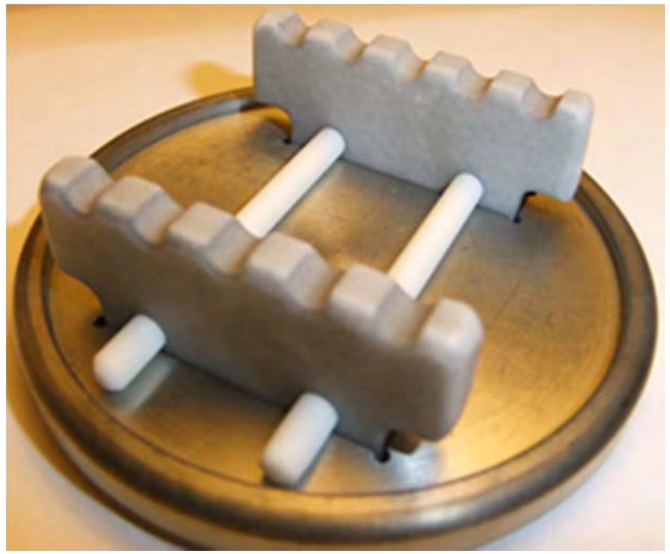
Top View

Side View

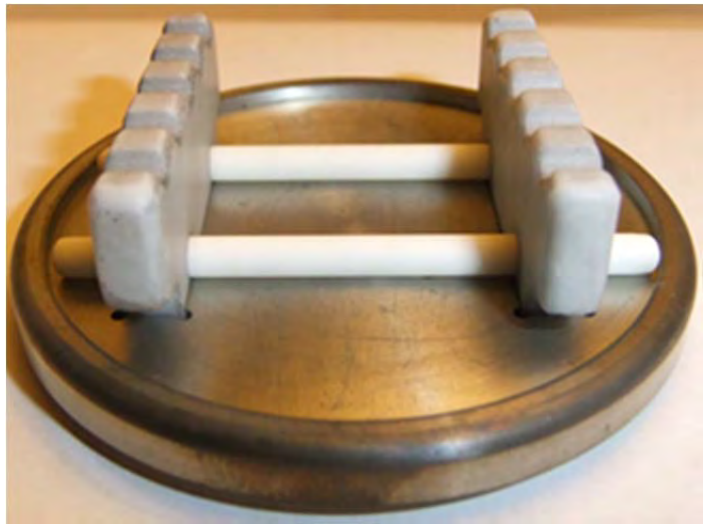
Figure FG18, Capped Ceramic Specimen Elevation Three One Quarter Inch Spaced Eighth Inch Slot T Stands



Labeled Slots View



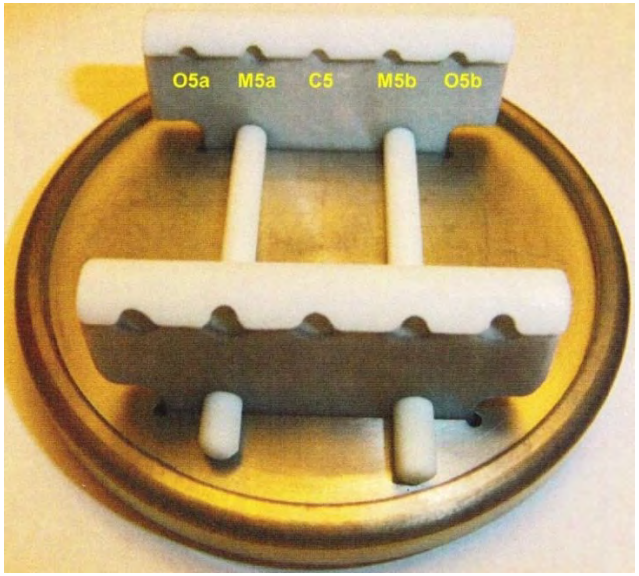
Side View



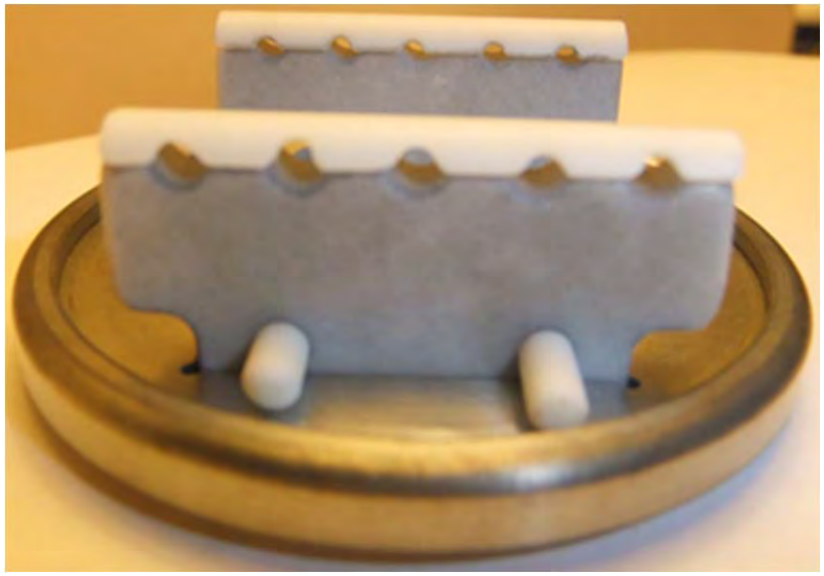
End View

Top View

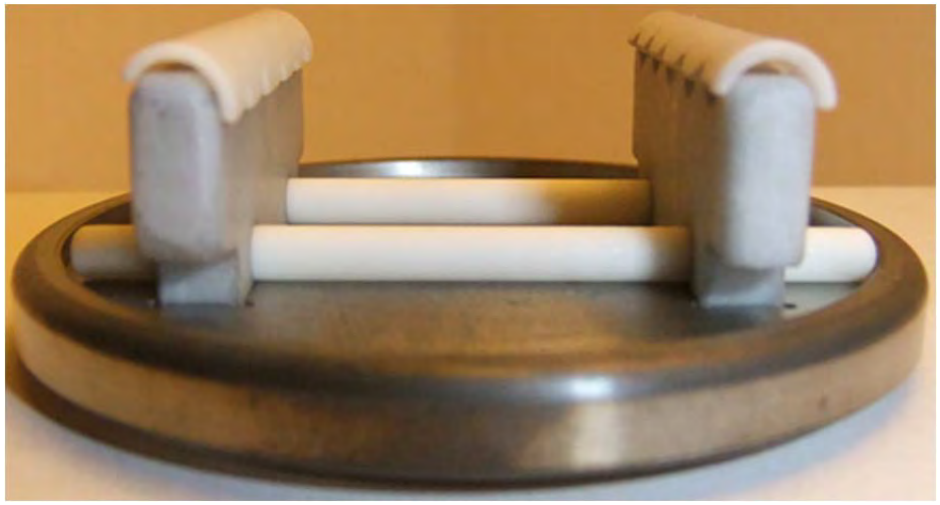
Figure FG19, Un Capped Ceramic Specimen Elevation Five One Quarter Inch Spaced Eighth Inch Slot T Stands



Labeled Slots View



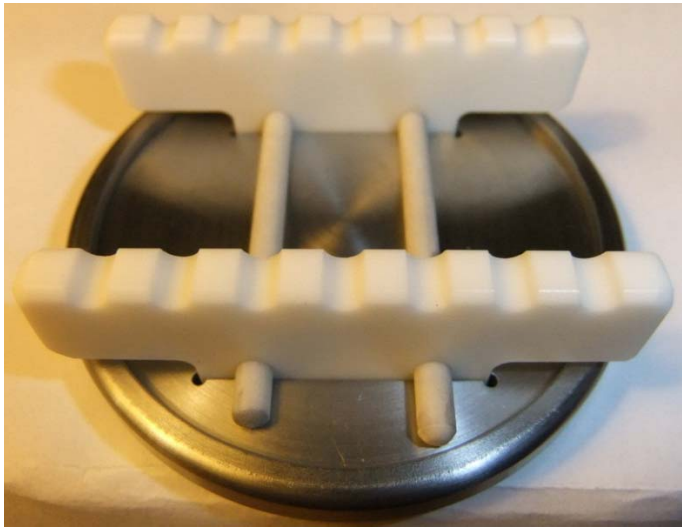
Side View



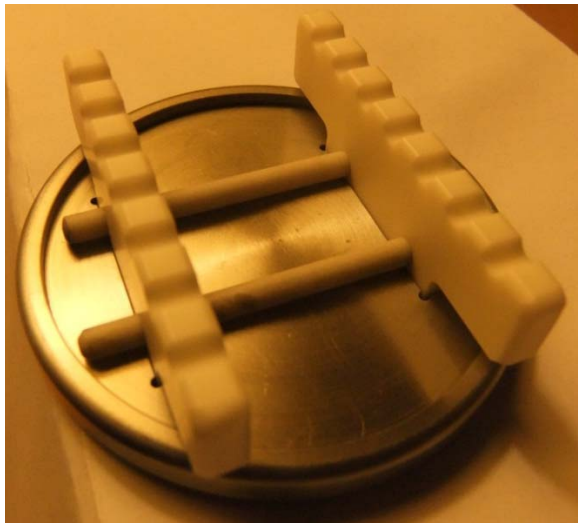
End View

Top View

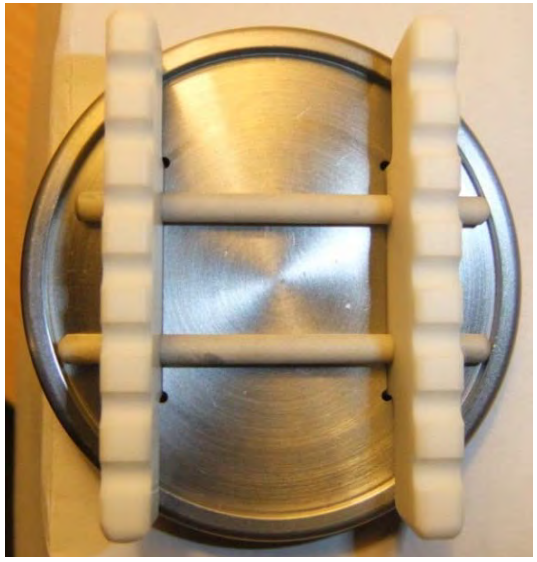
Figure FG20, Capped Ceramic Specimen Elevation Five One Quarter Inch Spaced Eighth Inch Slot T Stands



End View



Top Side View



Top View

Side View

Figure FG21, Un Capped Ceramic Specimen Elevation Seven One Quarter Inch Spaced Eighth Inch Slot T Stands

3.7 Section 7: Extractor

“Cleaning The Surface Finish Off Of YS80 With Soxhlet Extraction”

Aaron Sprague, University Of Dayton Research Institute

Soxhlet Extractor Design.

- Fiber Holder

The main chamber for the design of soxhlet extractor used provided no internal structures to support the fiber bundles. When fiber bundles were loosely placed in the main chamber, fibers were lost during the siphoning process. A four and a half inch glass tube was used to provide the necessary structural support for fiber holders. Fiber holders were machined out of three eighths inch diameter Teflon rod, with one eighth by five sixteenths inch notches cut into both ends to provide stability. Eighth inch holes were drilled through the rods at eighth inch intervals, designed for a fiber bundle to be placed in each hole. A perpendicular hole was drilled halfway through the rod into the each fiber bundle hole and threaded for nylon set screws. The nylon set screws served to securely hold each fiber bundle to the Teflon rod. Two different size holders were used in the extractors, one two and a half inch holder containing seven holes and two two inch holders containing five holes each. The center hole in each fiber holder was left empty to enable the holders to be lowered into and removed from the main chamber of the soxhlet extractor.

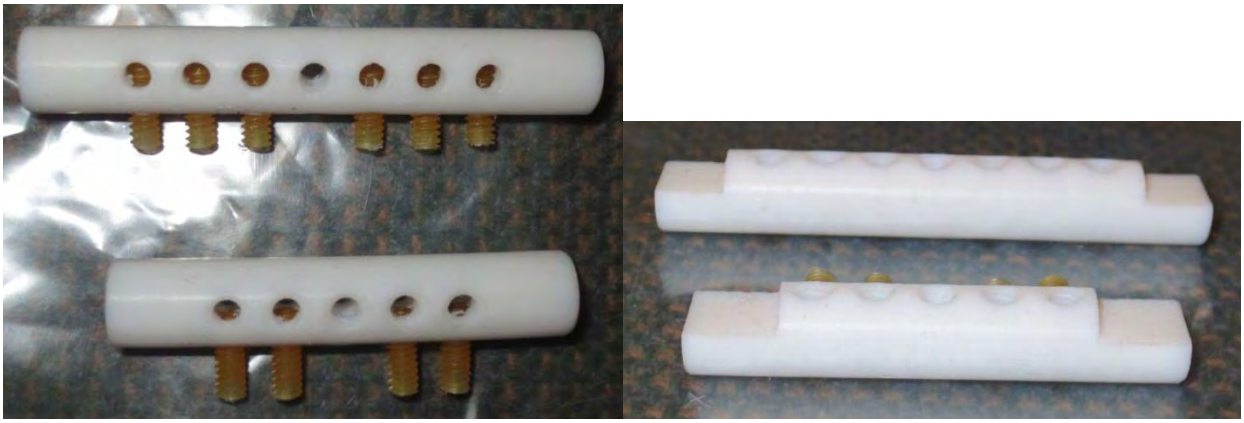


Figure FG22, Seven (top) and five (bottom) fiber holders.

The fiber holders were lowered and removed from the extractor by an aluminum rod with different thread sizes (eighth inch, sixteenth inch) machined on the rod. The sixteenth inch thread was used to tighten the nylon set screws on the fiber holders and the eighth inch was used for the fiber holders.

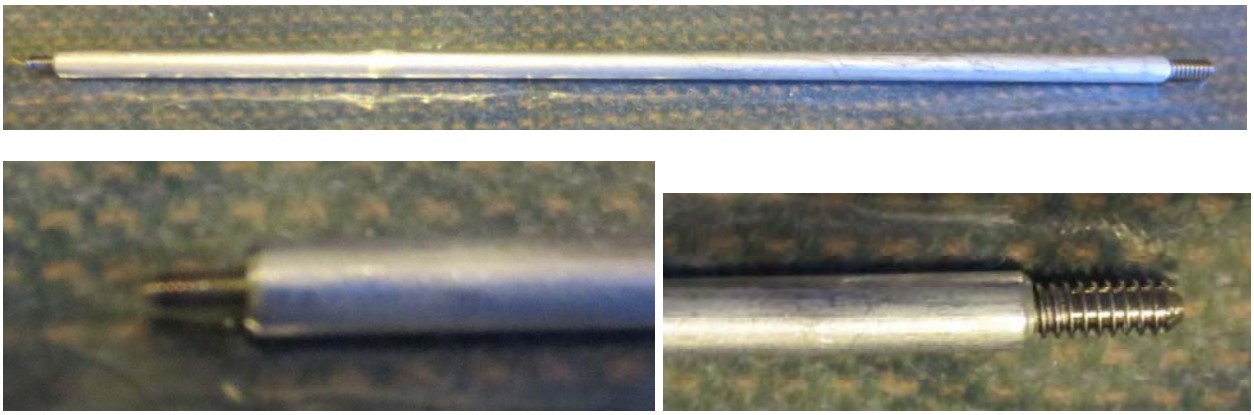


Figure FG23, Fiber holder retriever.

Figure FG24, Main chamber of Soxhlet extractor.

Figure FG25, Main chamber filling with condensed acetone.

Figure FG26, Soxhlet extractor setup.

A loading station was machined to consistently load the fiber bundles into the fiber holders. The loading station consisted of a Teflon® channeled bed, aluminum base, ten screws, and two Teflon® fiber braces. The channeled bed consisted of channels eighth inch intervals, with notches cut quarter inch by three quarter inch into each end of the bed.

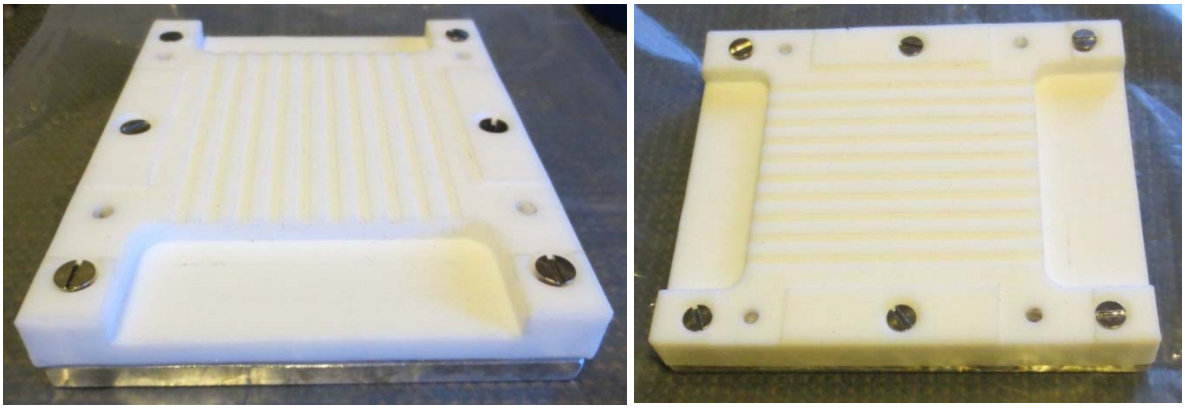


Figure FG27, Channel assembly bed.

The fiber holder is placed in the notch of the channeled bed, aligning the channels with the fiber bundle holes and with the notches on the fiber holder facing the channels. A fiber bundle was placed in each aligned channel and pushed through the fiber holder so that approximately half inch of the fiber bundle was on the other side. Two braces spanning the width of the bed were screwed into place to secure the fiber bundles on the bed while the nylon set screws were tightened on the fiber holders.

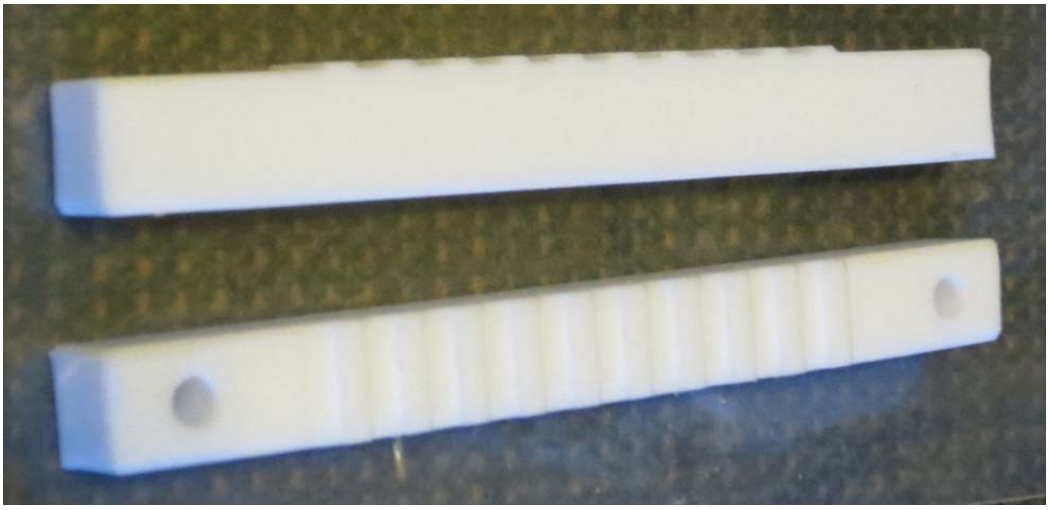


Figure FG28, Fiber braces.

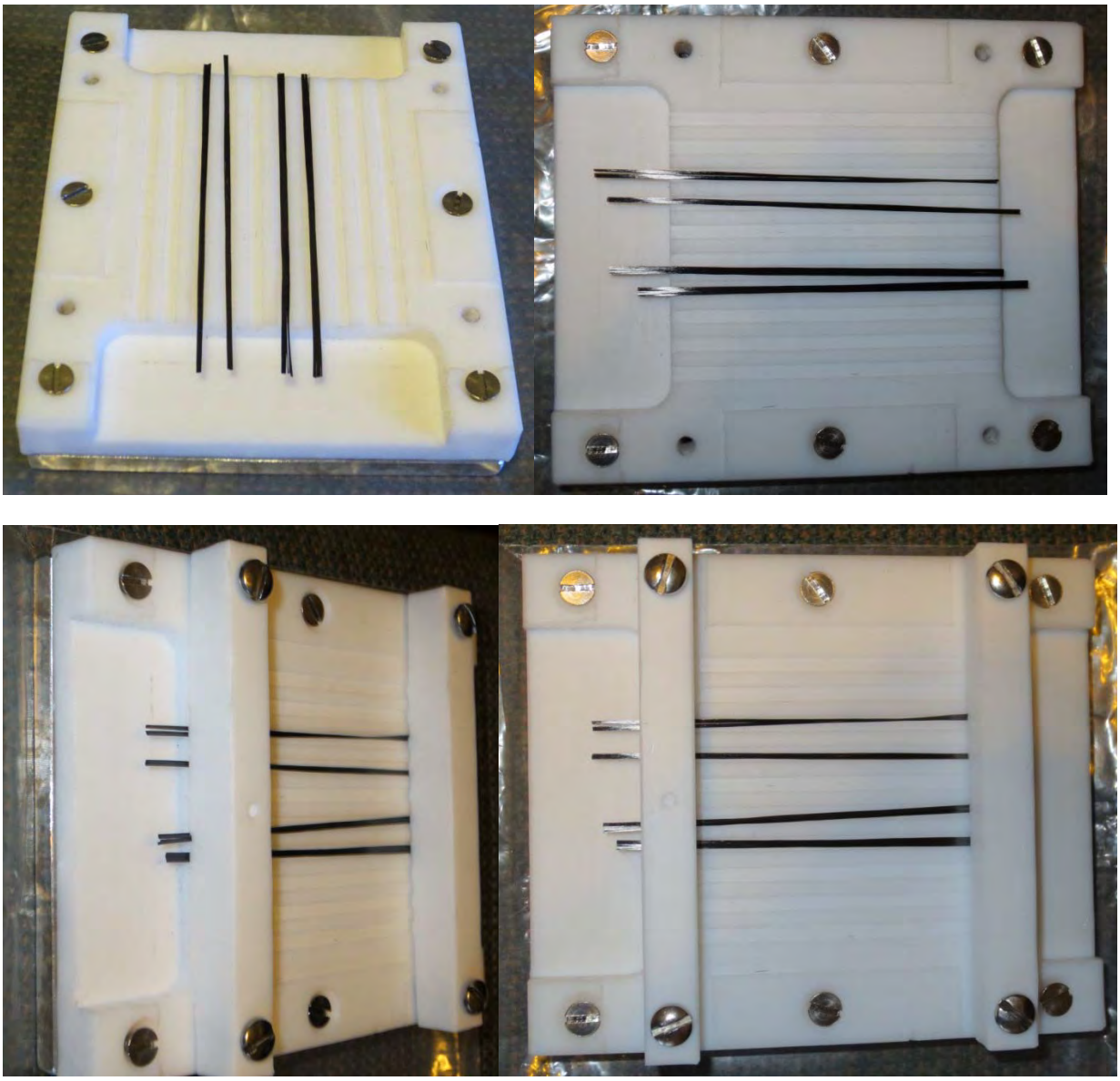


Figure FG29, Channeled assembly bed with fibers (top) and braces (bottom).

Aluminum base provided support for the screws used to hold the braces. The braces contained knobs corresponding to the channels of the bed. Once all set screws were tightened, the braces were removed and the fiber holder and attached fiber bundles were lowered into the soxhlet extractor threading the aluminum rod through the open center hole on each fiber holder.

All items besides the soxhlet extractors, screws used on the loading station, and nylon set screws were custom machined.

- Cleaning equipment

Ultrasonic cleaning was performed on all equipment that came in contact with the each set fiber bundles during surface finish removal or post-removal. Items that came in contact with the fibers prior to

surface finish removal were periodically ultrasonic cleaned as needed. Cleaning sequence consisted of one wash cycle and five rinse cycles. Wash cycle consisted of ultrasonic wash with double-distilled water and Alconox® soap for one hour. Rinse cycles consisted of ultrasonic rinse with double-distilled water for various durations; first rinse for one hour, second and third rinse for thirty minutes each, and fourth and fifth rinse for fifteen minutes each. All cleaned items were dabbed dry with Kimwipes®. Individual items were sealed in new plastic bags until next usage.

- Cooling water

A refrigeration chilling unit was to control cooling fluid supply and temperature. The cooling fluid used in the chiller was a mixture of water and isopropanol. The cooling fluid was pumped from the chiller reservoir through the two condensing columns in series and returned to the chiller reservoir, creating a closed loop system. The temperature of the cooling fluid in the chiller was set at 10^{o}C in order to provide sufficient cooling and minimize loss of acetone. Lower temperatures were achievable, but were not used in order to mitigate the amount of condensation formed on the supply and return cooling fluid tubes.

Figure FG30, Soxhlet extractor setup in chemical hood and refrigeration unit.

- Soxhlet Extractor

YS80 fibers contained a surface finish that prevented fin growth on the surface of the fibers.

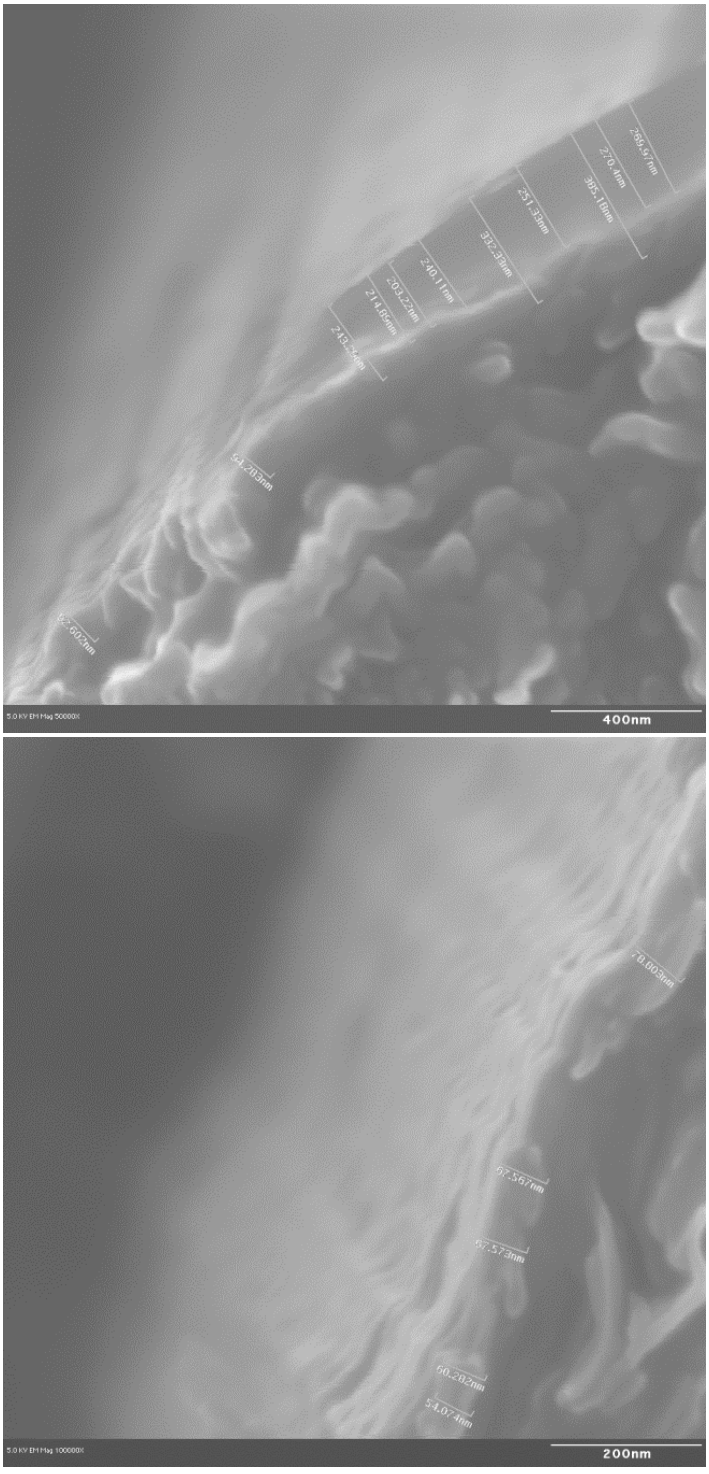


Figure FG31, Surface finish thickness.

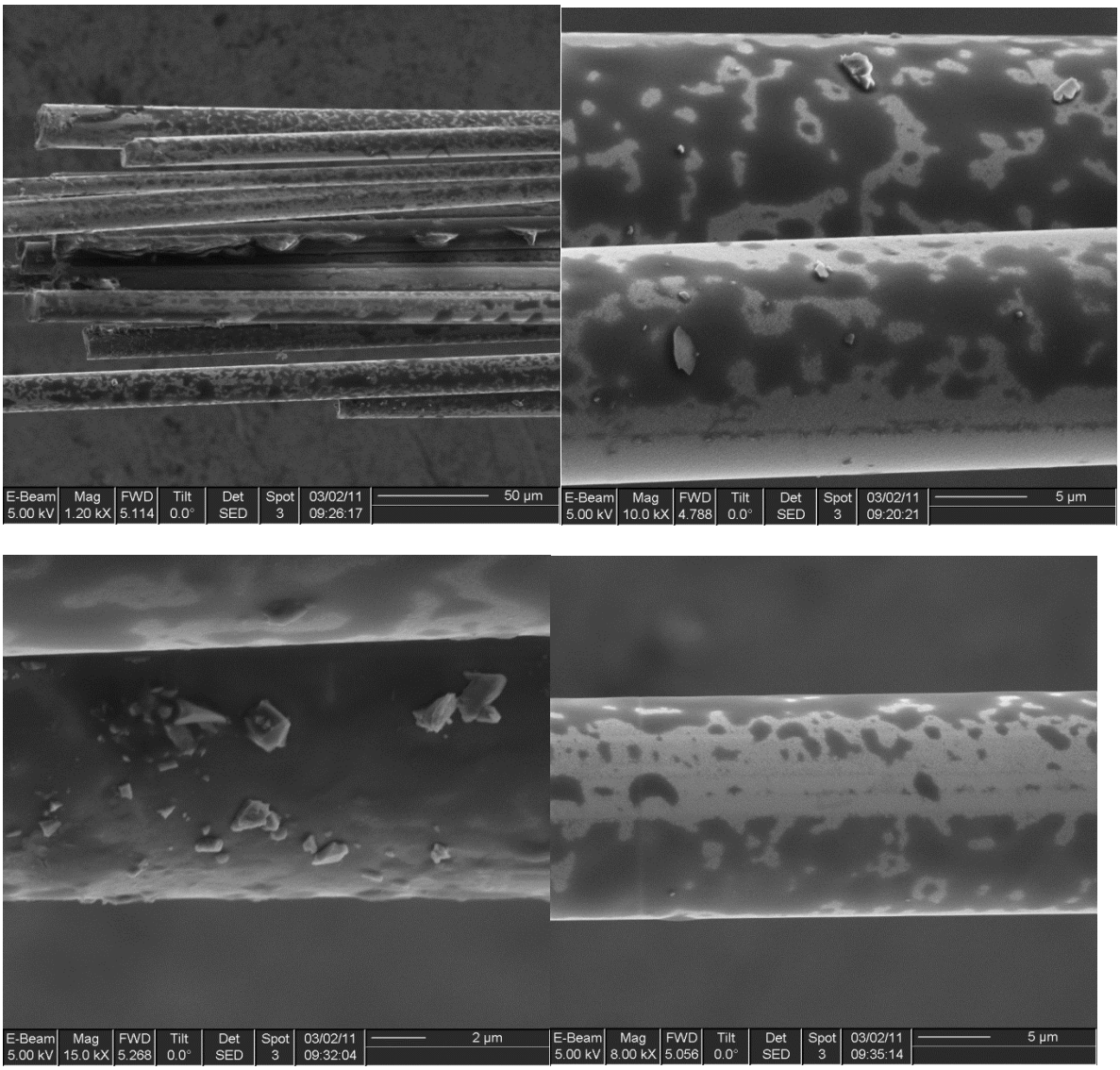


Figure FG32, YS80 with surface finish fin growth attempt.

Soxhlet extractor was selected on the theory that all or majority of the surface finish on the YS80 fibers, once stripped, would not volatilize back into the Soxhlet extractor. Acetone was chosen for its organic solvent properties. Each two liter round bottom flask was filled approximately three quarters full with ACS reagent grade acetone.

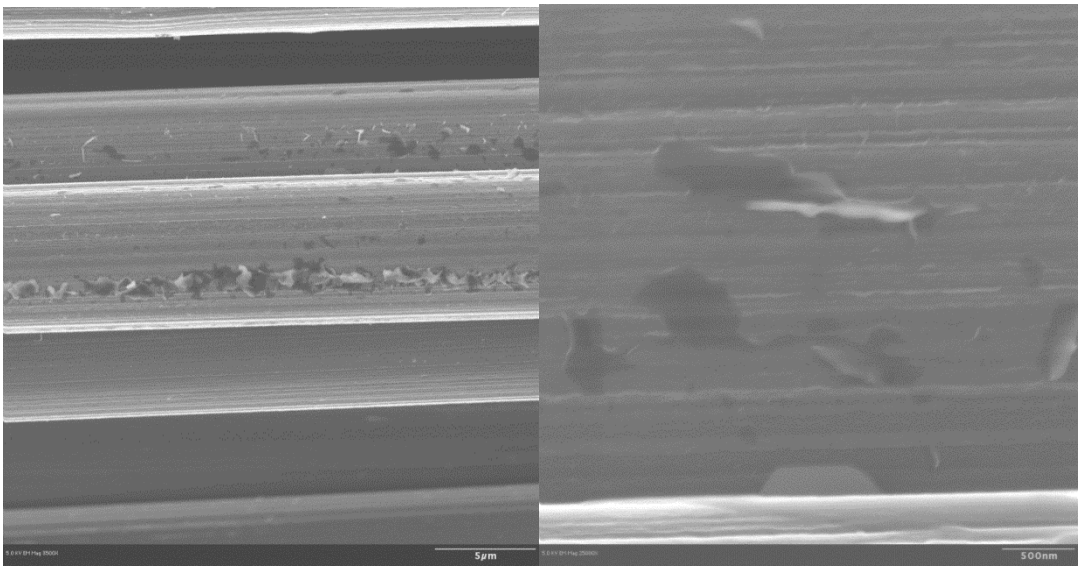


Figure FG33, Test Bundle Five days cleaning with ACS reagent grade acetone.

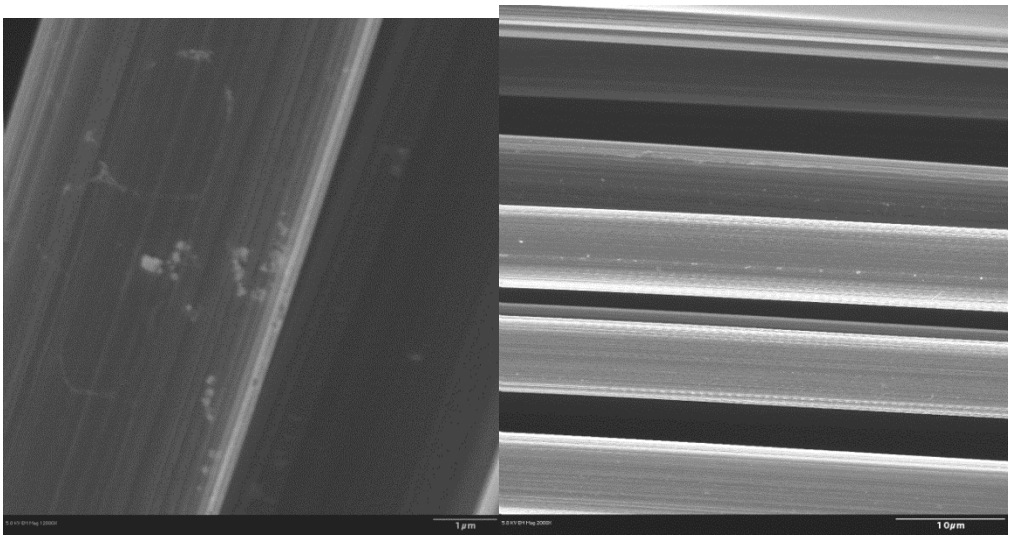


Figure FG34, Test Bundle Seven days cleaning with ACS reagent grade acetone.

It was tested and shown that Technical grade acetone provided unsatisfactory surface finish removal, the surface finish material would form into large clumps and long ribbons on the fibers.

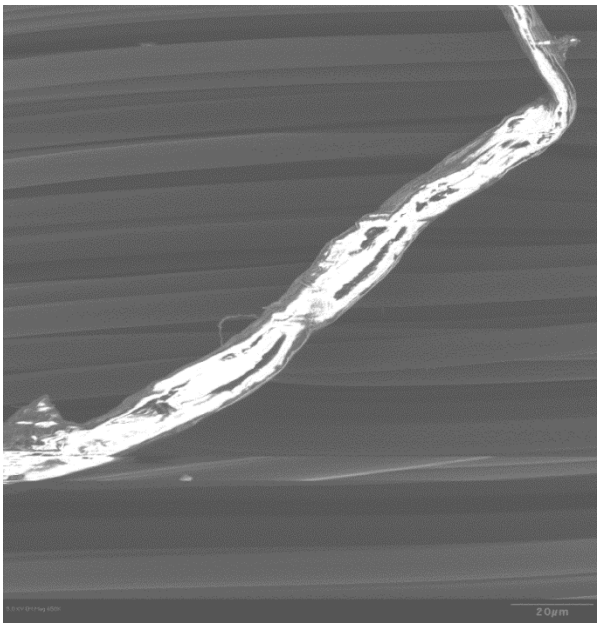


Figure FG35, Ribbon of surface finish after cleaning with Technical grade acetone.

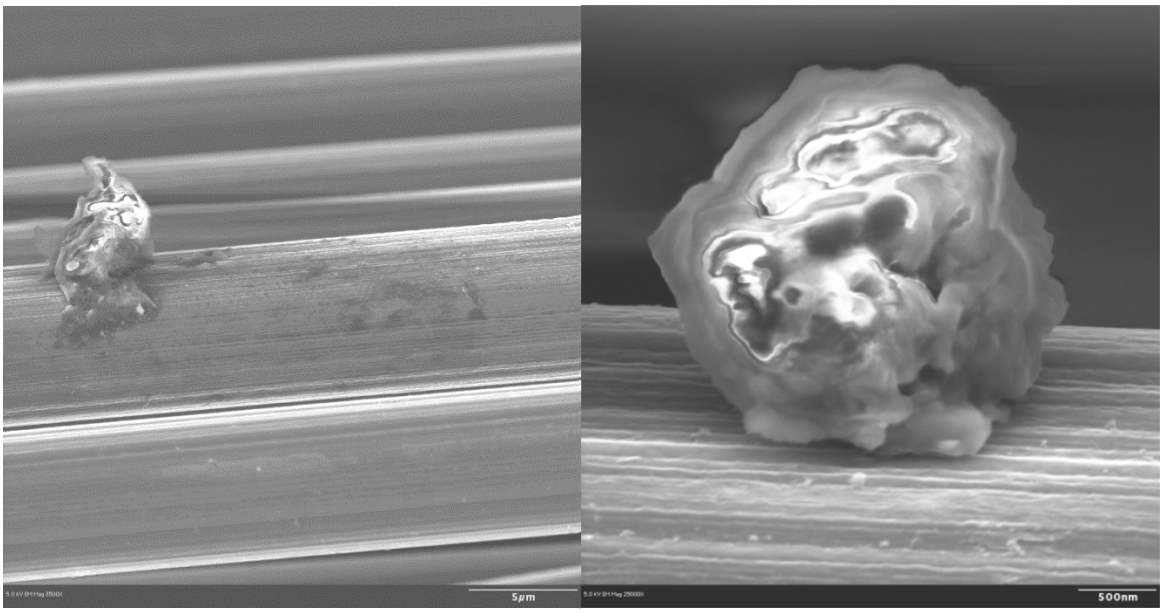


Figure FG36, Ball of surface finish after cleaning with Technical grade acetone.

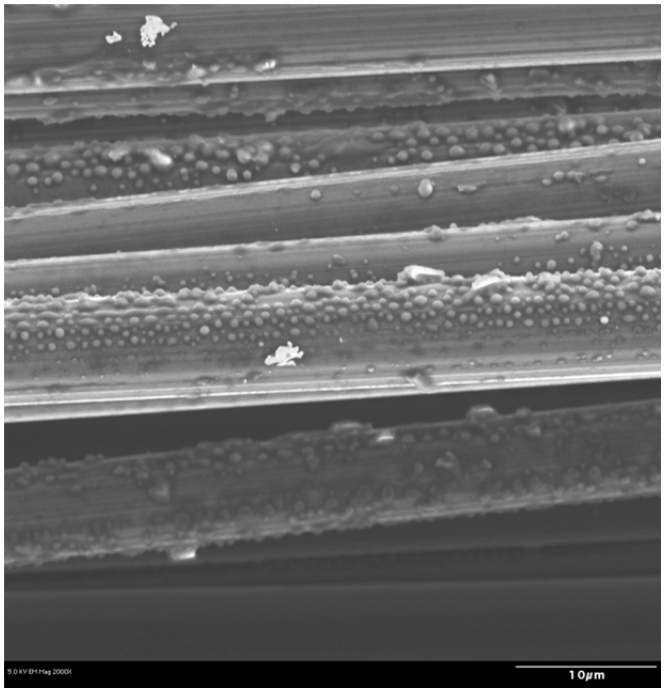


Figure FG37, Four weeks cleaning with used Technical grade acetone.

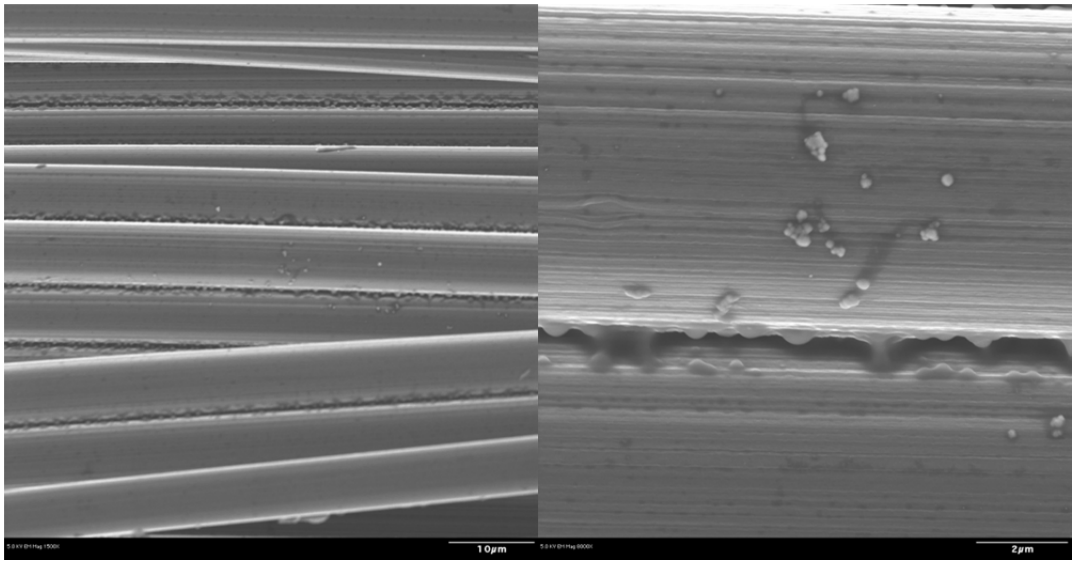


Figure FG38, Four weeks cleaning with new Technical grade acetone.

Teflon® boiling stones were placed in the bottom of the round bottom flask. Heating mantles were used to provide the heat input to volatize the acetone. The voltage to the heating mantle was controlled through a variable autotransformer. The voltage to the heating mantle was set to provide heat input to complete an entire cycle in the Soxhlet extractor approximately once every 20 minutes.

The cycle of the Soxhlet extractor consists of three steps: volatilization, condensation and collection, and siphoning. When sufficient heat is applied to the acetone solvent, it volatizes out of the round bottom flask and up the side arm of the Soxhlet extractor. The acetone vapor condenses on the cooled condensing column and drips into the Soxhlet extractor's main chamber. At a specific height in the main chamber, a suction head is formed and the mixture of liquid acetone and surface coating is siphoned back into the round bottom flask; completing one cycle.

Complete stripping of surface finish off of 14 fiber bundles in each extractor required four continuous weeks of stripping.

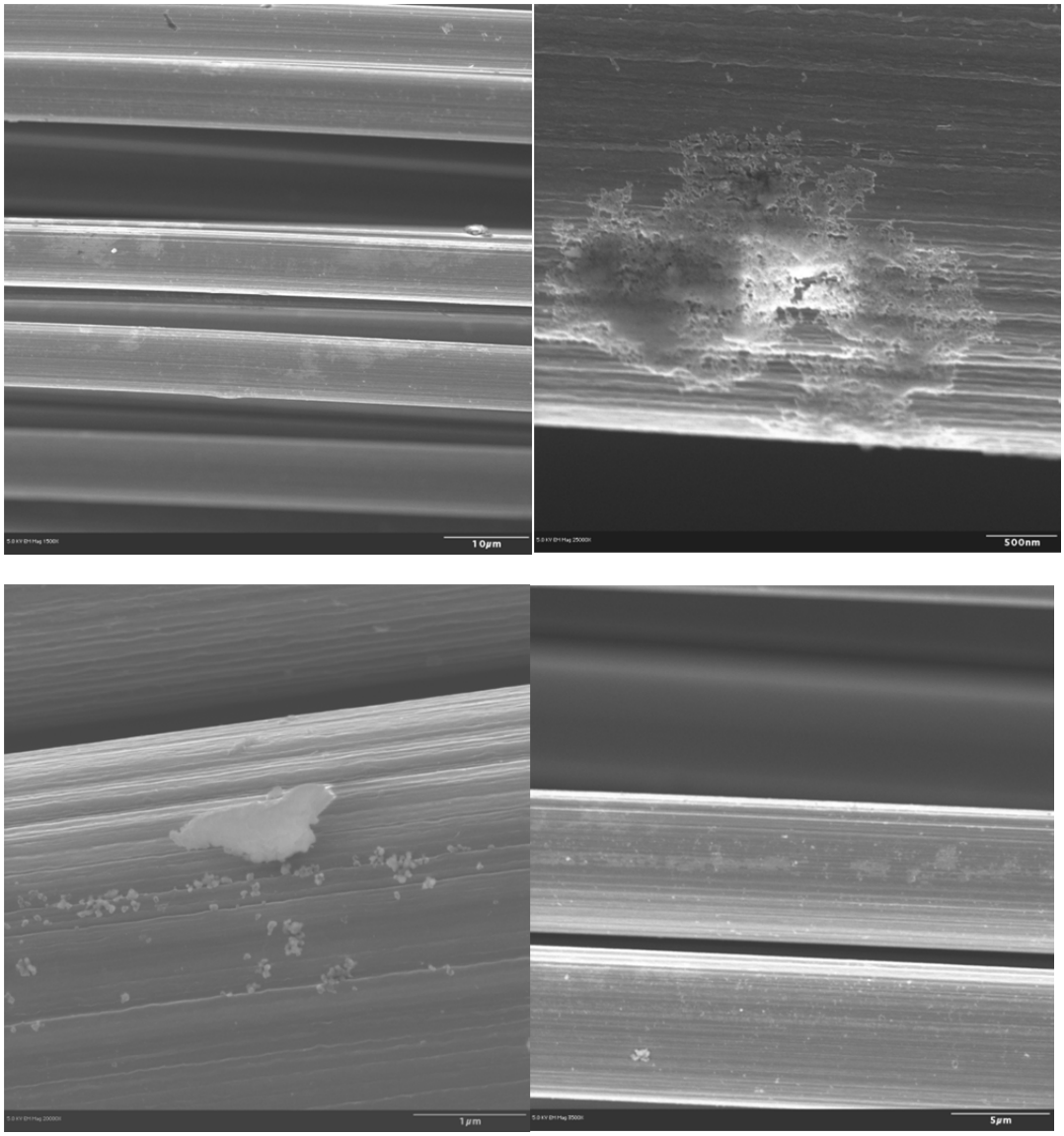


Figure FG39, One week clean in ACS reagent grade acetone.

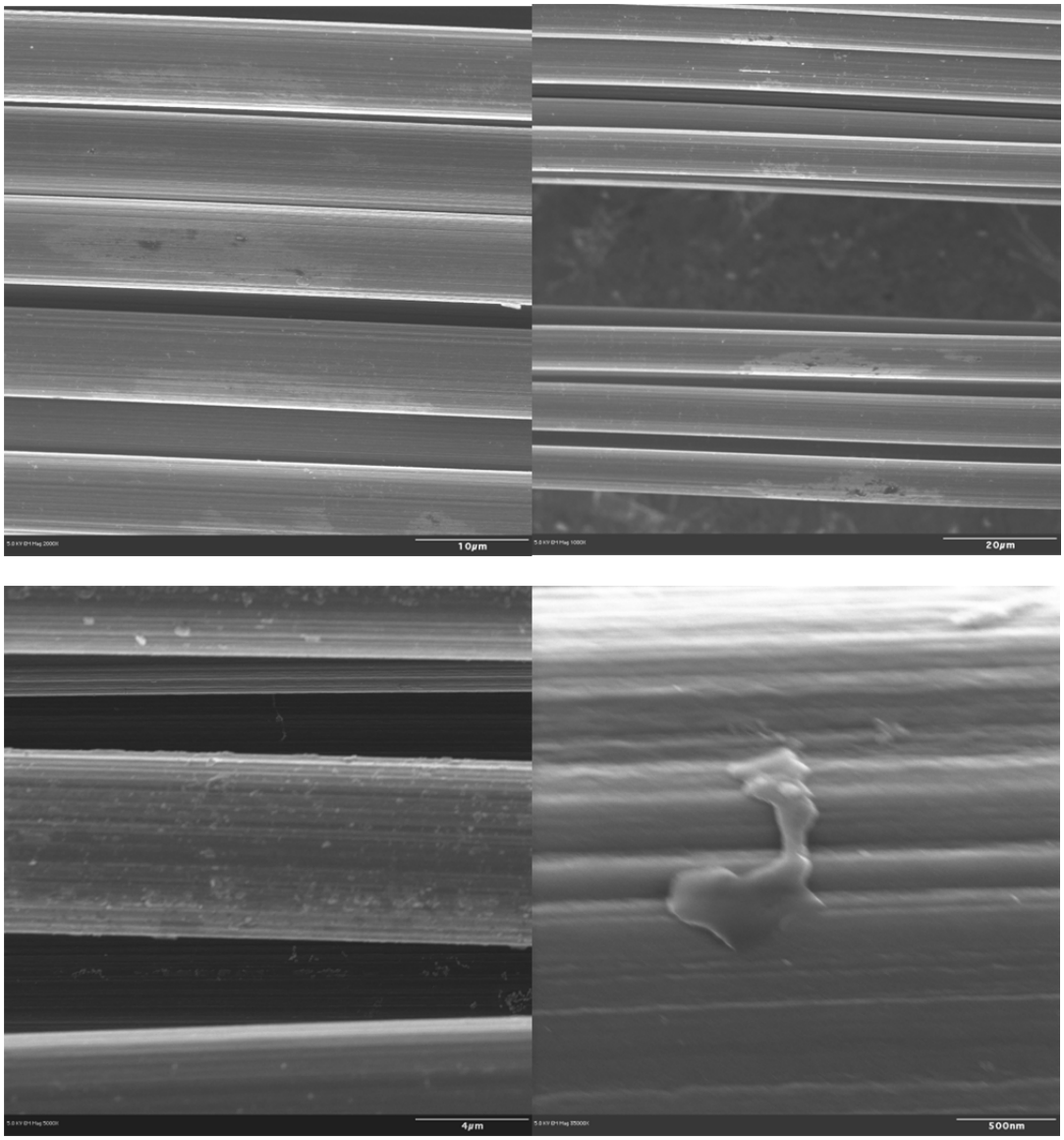


Figure FG40, Two week clean in ACS reagent grade acetone.

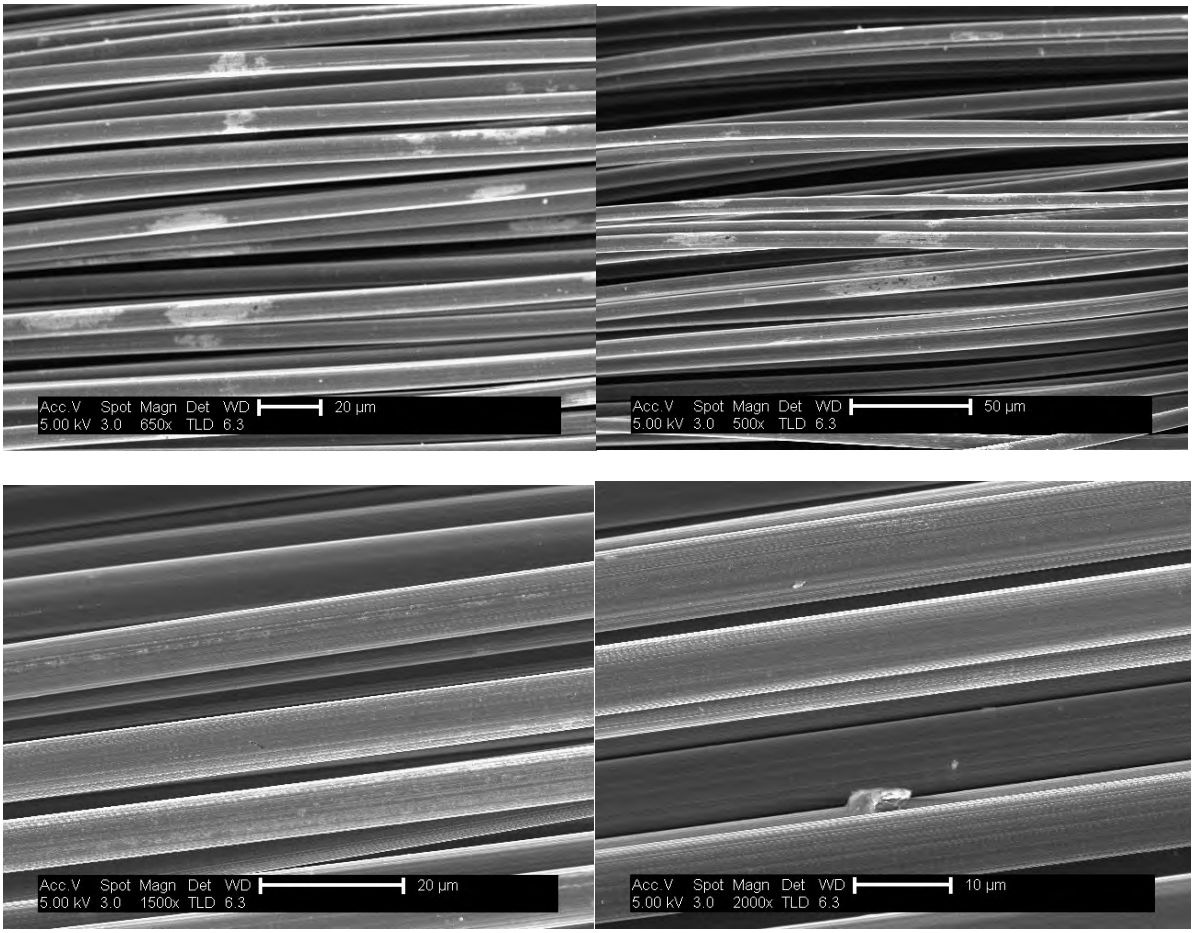


Figure FG41, Two weeks cleaning with ACS reagent grade acetone, methanol rinse.

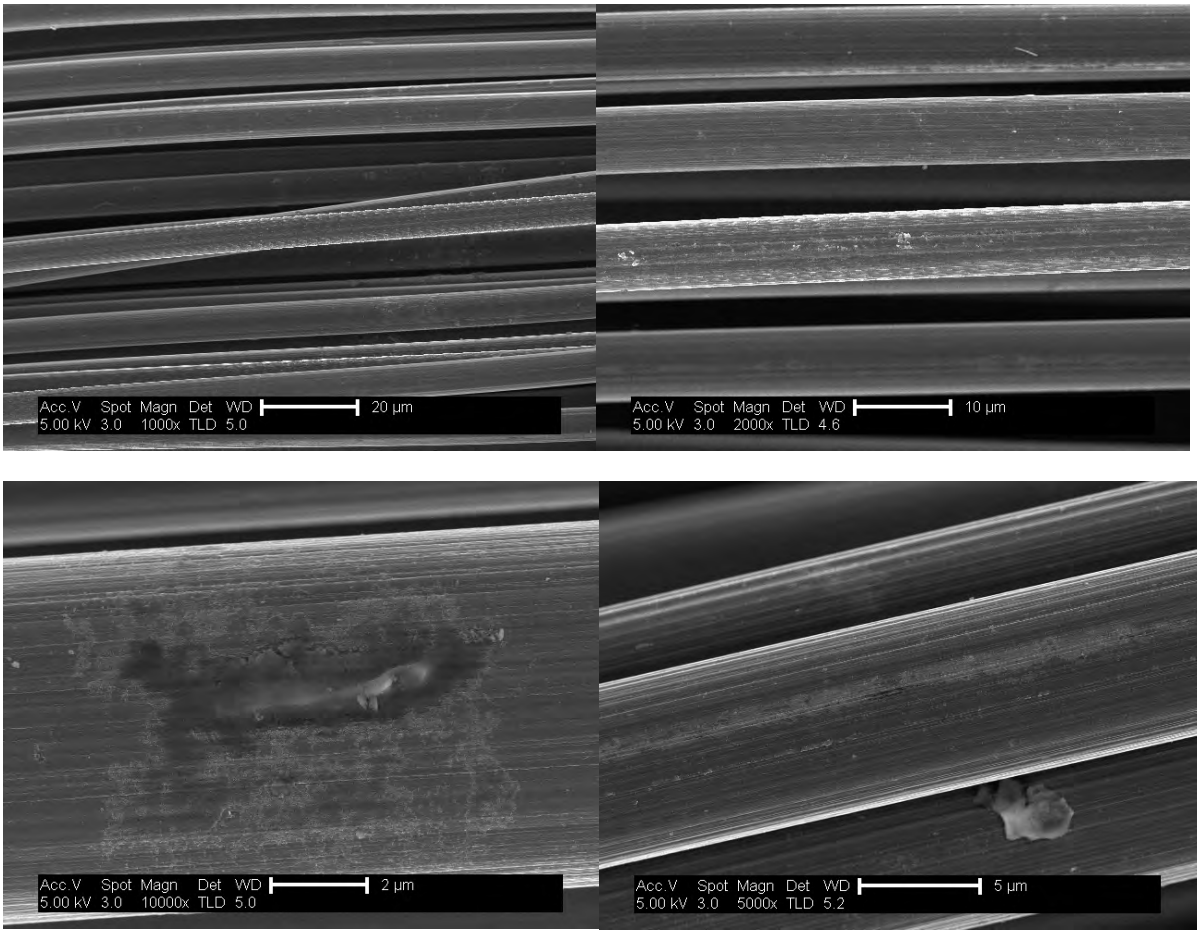


Figure FG42, Three weeks cleaning with ACS reagent grade acetone.

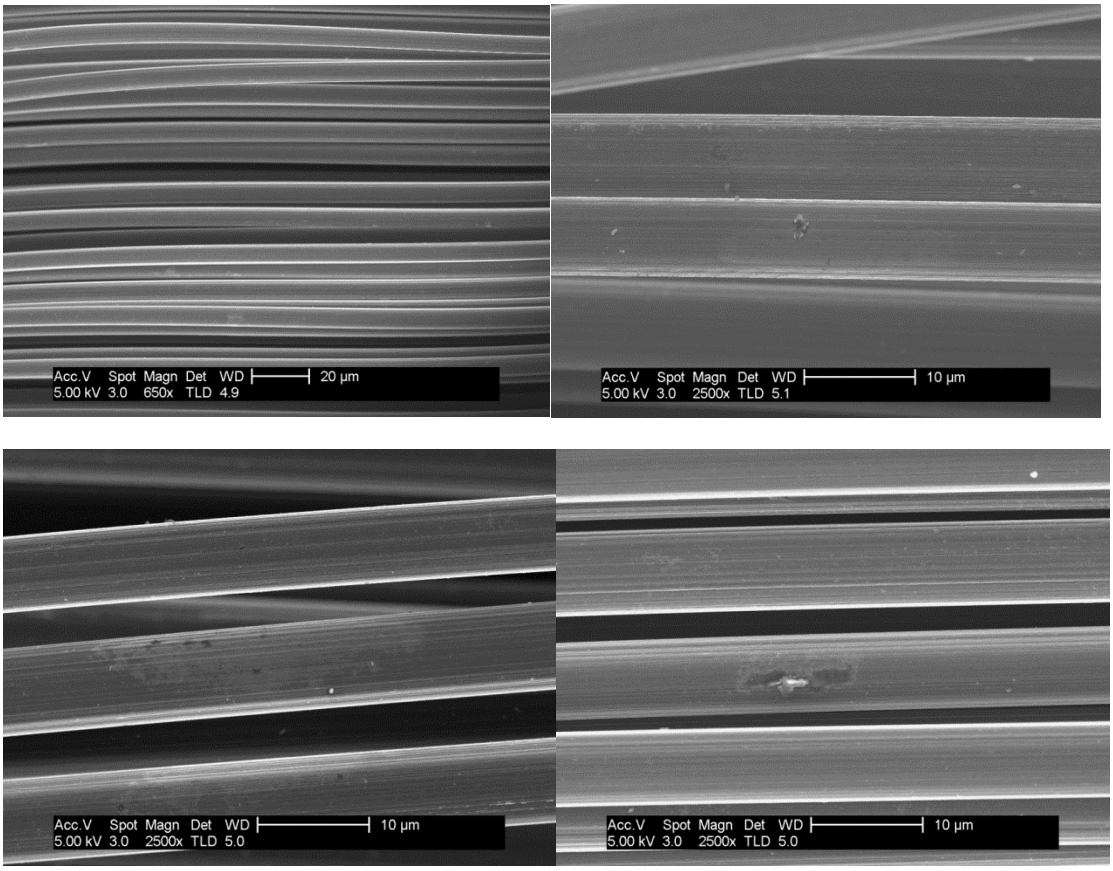


Figure FG43, Four weeks cleaning with ACS reagent grade acetone.

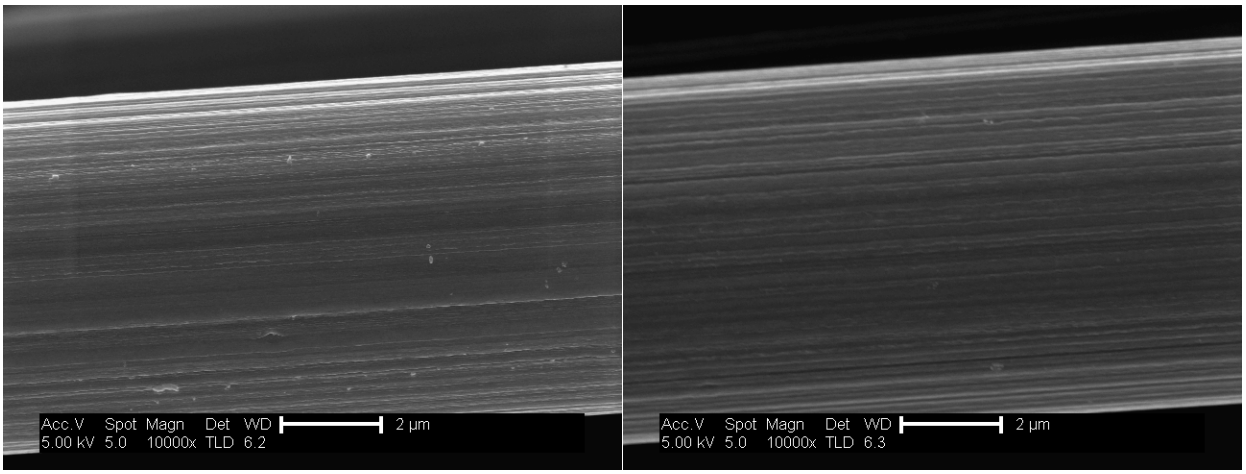


Figure FG44, Four weeks cleaning with ACS reagent grade acetone, methanol rinse.

Diminishing returns were observed over the four week period. Placing non-finish YSH50 fibers in the Soxhlet extractor for one week using the used acetone resulted in small deposits of finish onto the fibers, concluding that some of the finish was volatizing with the acetone.

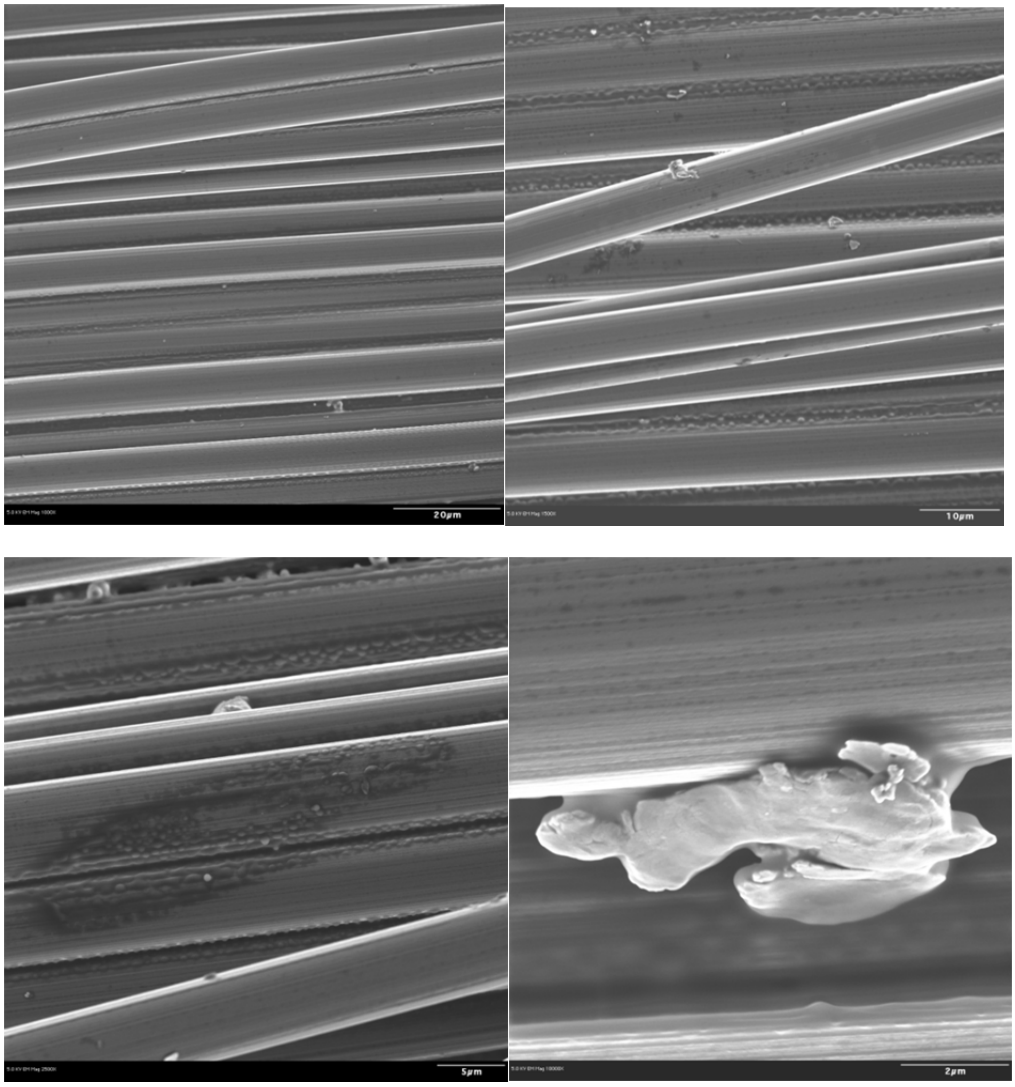


Figure FG45, Surface finish residue deposits on YSH50 fibers cleaned for one week in used Technical grade acetone.

Several post-Soxhlet extractor cleaning methods were tested. Ultrasonic rinse and stir bar rinse in double-distilled water were effective in removing surface finish deposits, but resulted in breakages in the fibers. Rinsing fibers with methanol after removal from soxhlet extractor resulted in less coating deposits and did not cause fiber breakage. Methanol rinses were immediately applied to all fiber bundles upon removal from the Soxhlet extractors.

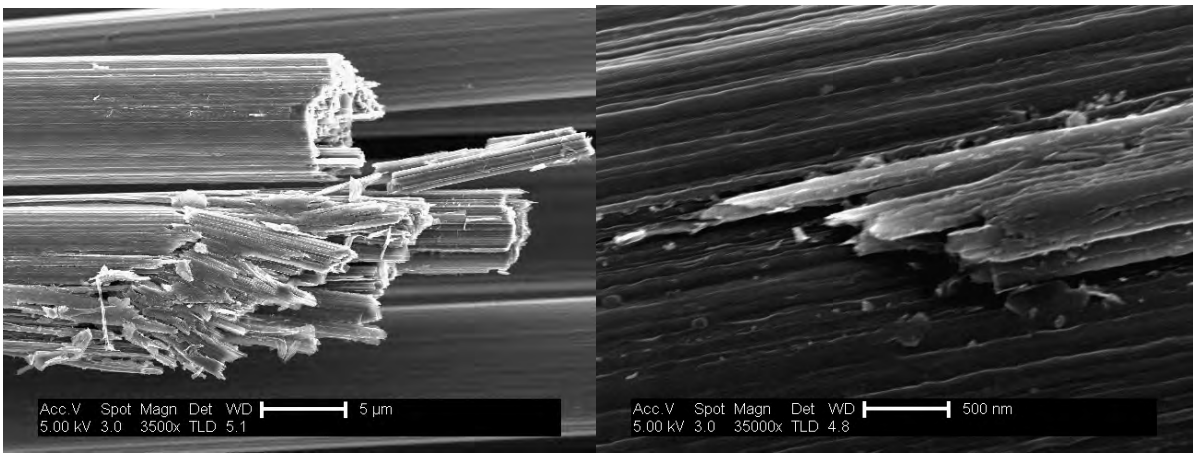


Figure FG46, Four weeks ACS reagent grade acetone cleaned, stir bar (left) and ultrasonic (right) rinse.

- Conclusion

Four weeks of continuous cleaning with ACS reagent grade acetone were required to strip the surface finish off of the YS80 fiber bundles in order that graphitic fins could be grown on the fiber surface. YS80 fiber bundles were not available without the surface finish. A Variety of cleaning methods were tested and those that provided the desired results were chosen, regardless of prevalence or lack thereof in an industrial setting. Removal of the surface finish was required to achieve the primary experimental objective; superior alternate cleaning methods that were not tested are plausible.

3.8 Section 8: YSH50A Fin Growth

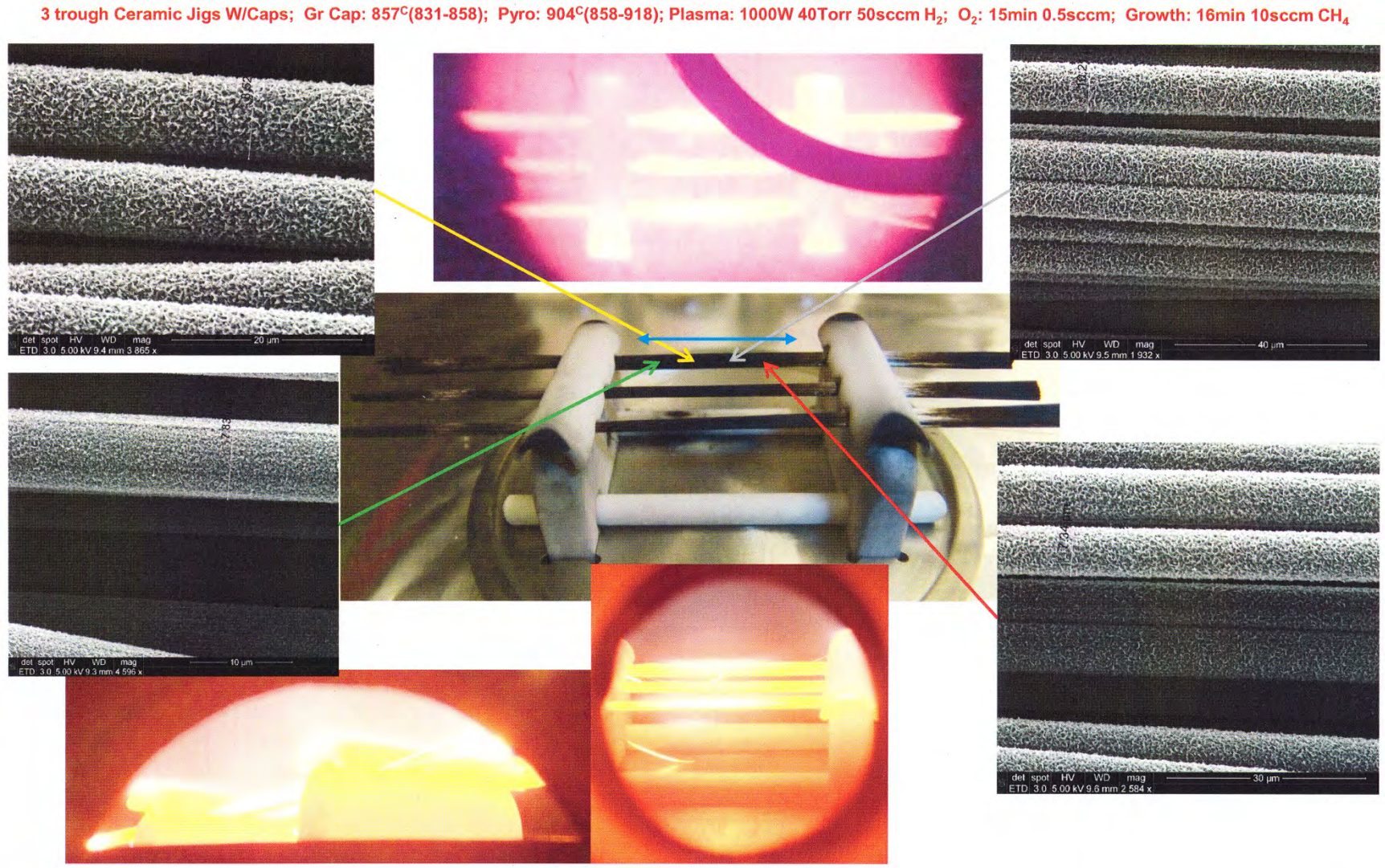


Figure FG47, YSH50A Fin Growth Capped Ceramic Jig O3a Position Surface View

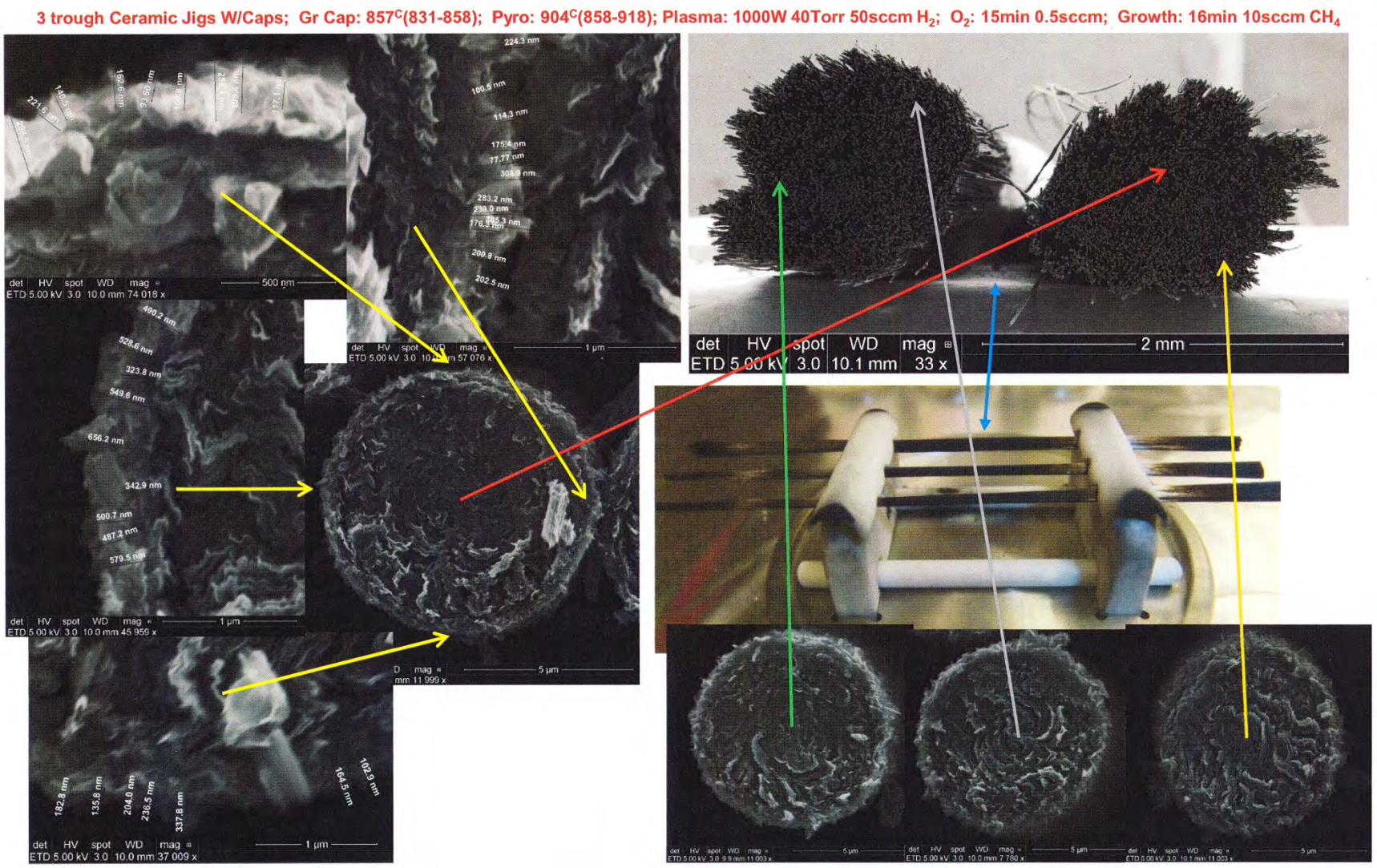


Figure FG48, YSH50A Fin Growth Capped Ceramic Jig O3a Position End View

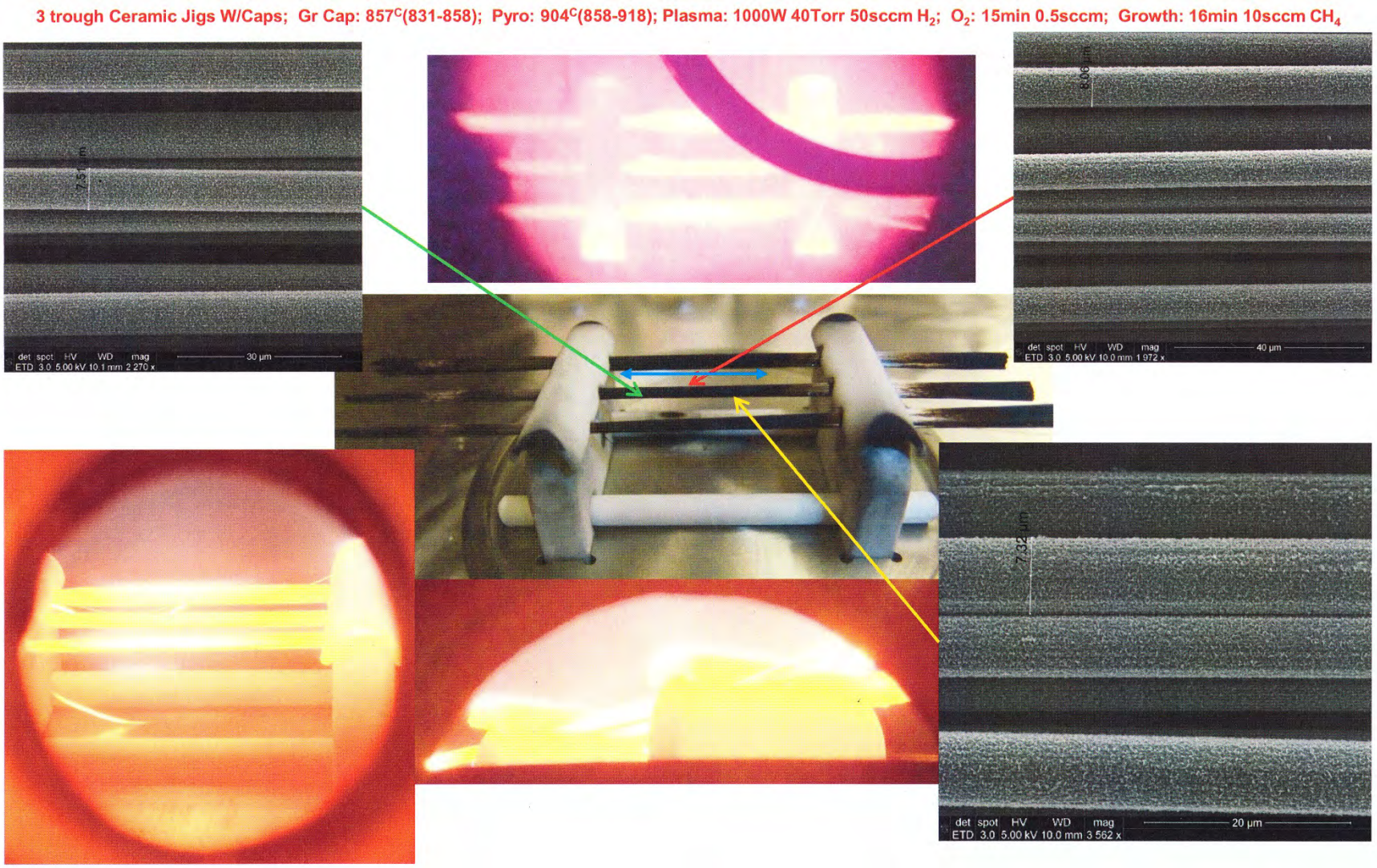


Figure FG49, YSH50A Fin Growth Capped Ceramic Jig C3 Position Surface View

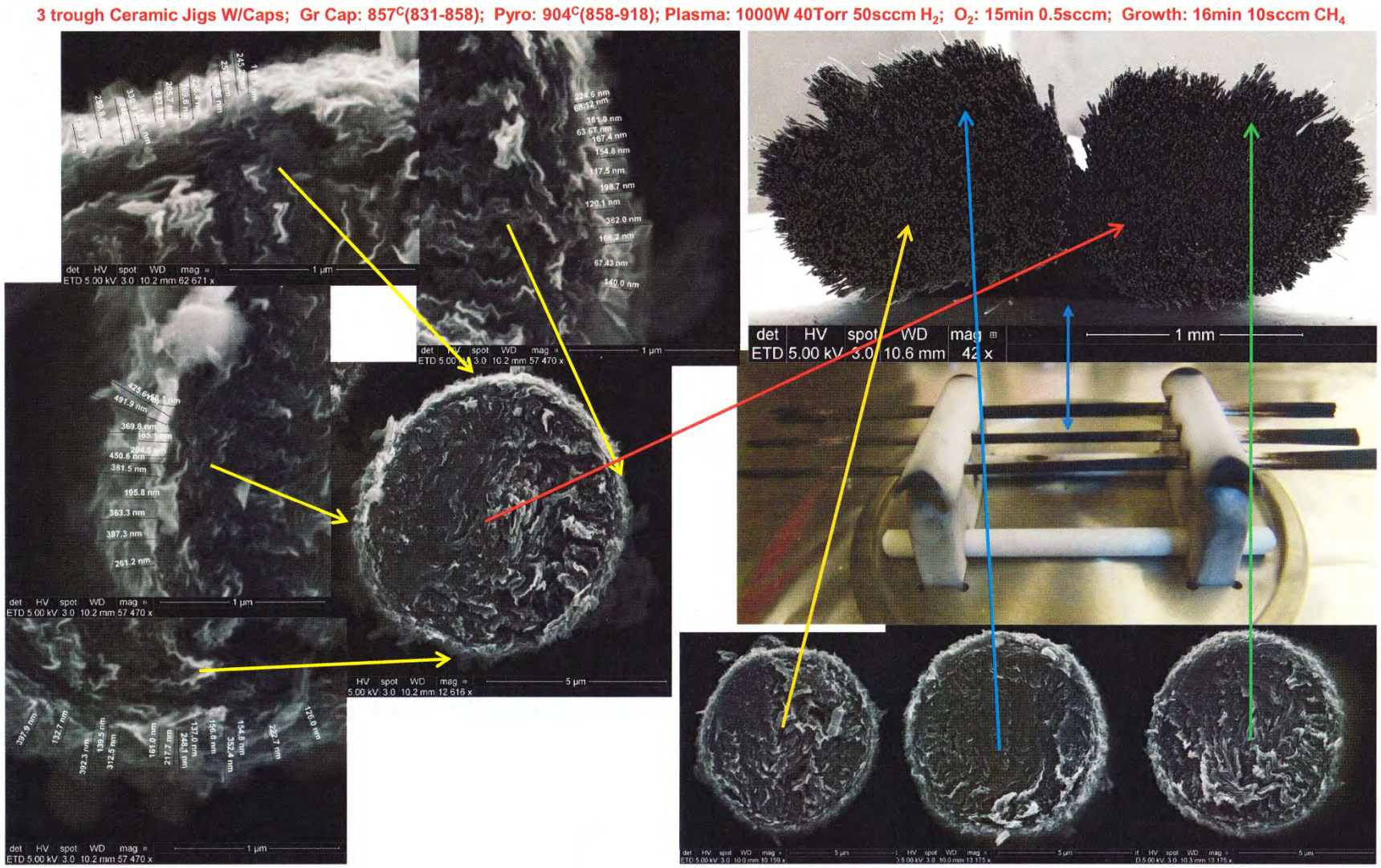


Figure FG50, YSH50A Fin Growth Capped Ceramic Jig C3 Position End View

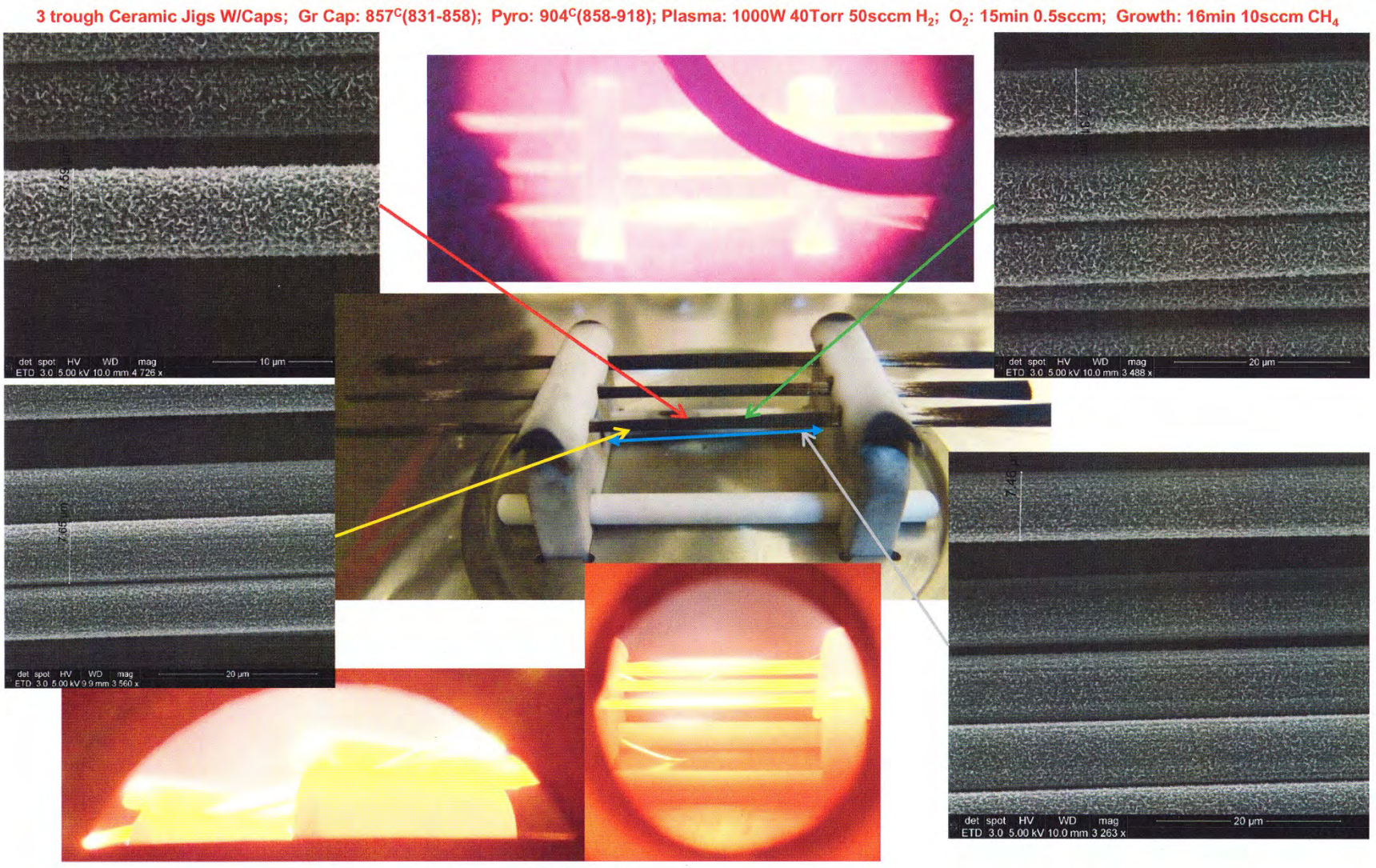


Figure FG51, YSH50A Fin Growth Capped Ceramic Jig O3b Position Surface View

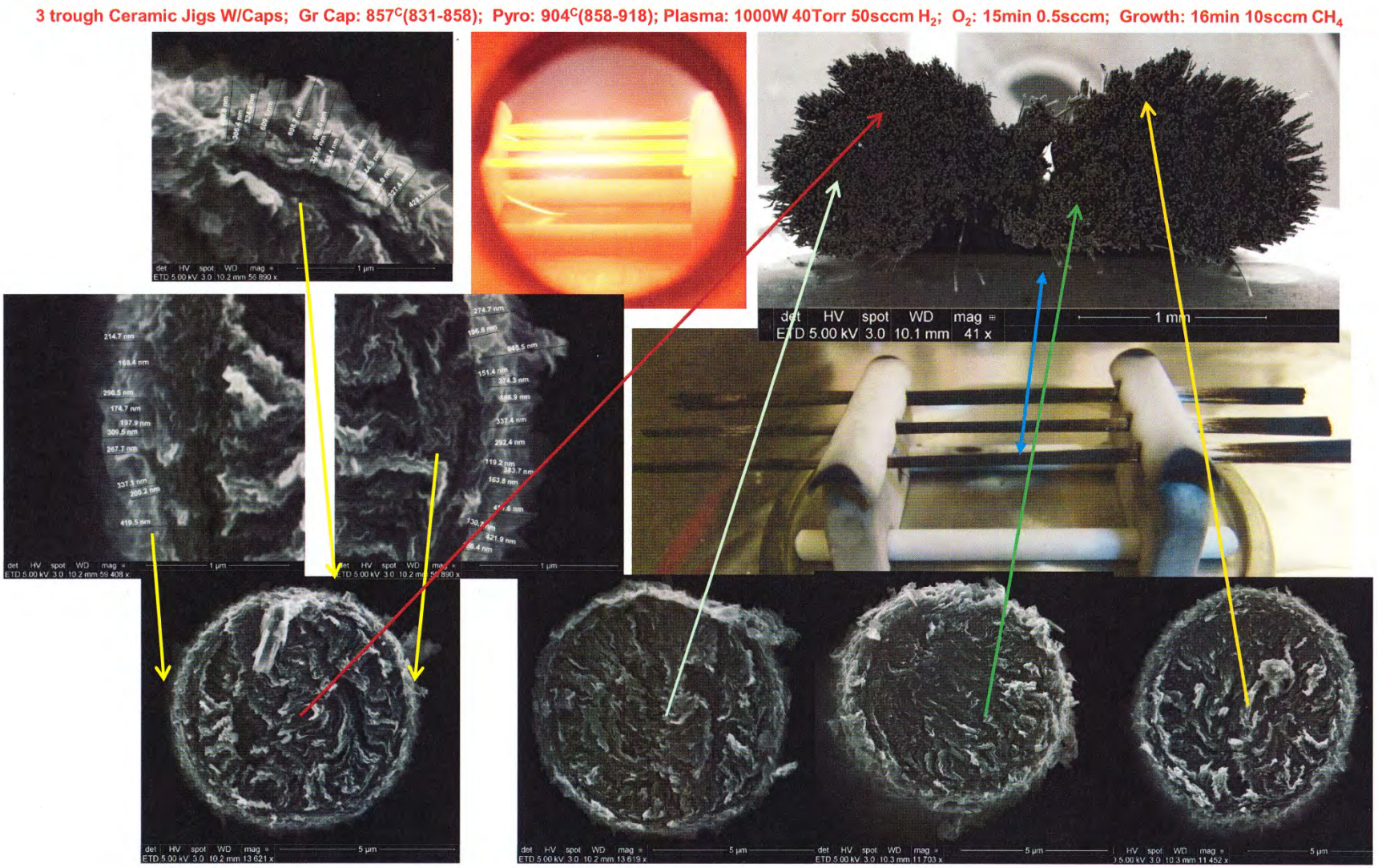


Figure FG52, YSH50A Fin Growth Capped Ceramic Jig O3b Position End View

3.9 Section 9: M55JB Fin Growth

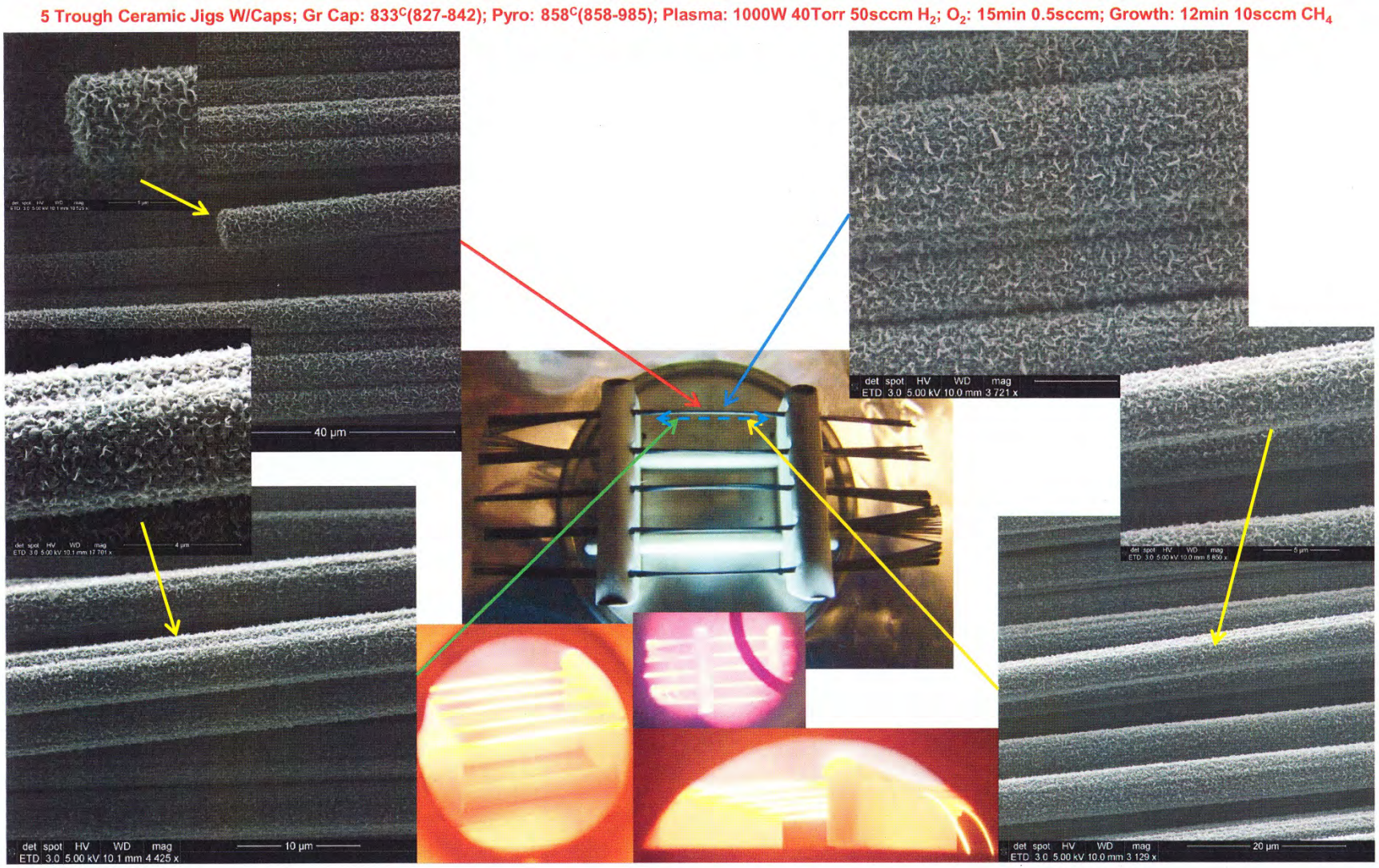


Figure FG53, M55JB Fin Growth Capped Ceramic Jig O5a Position Side View

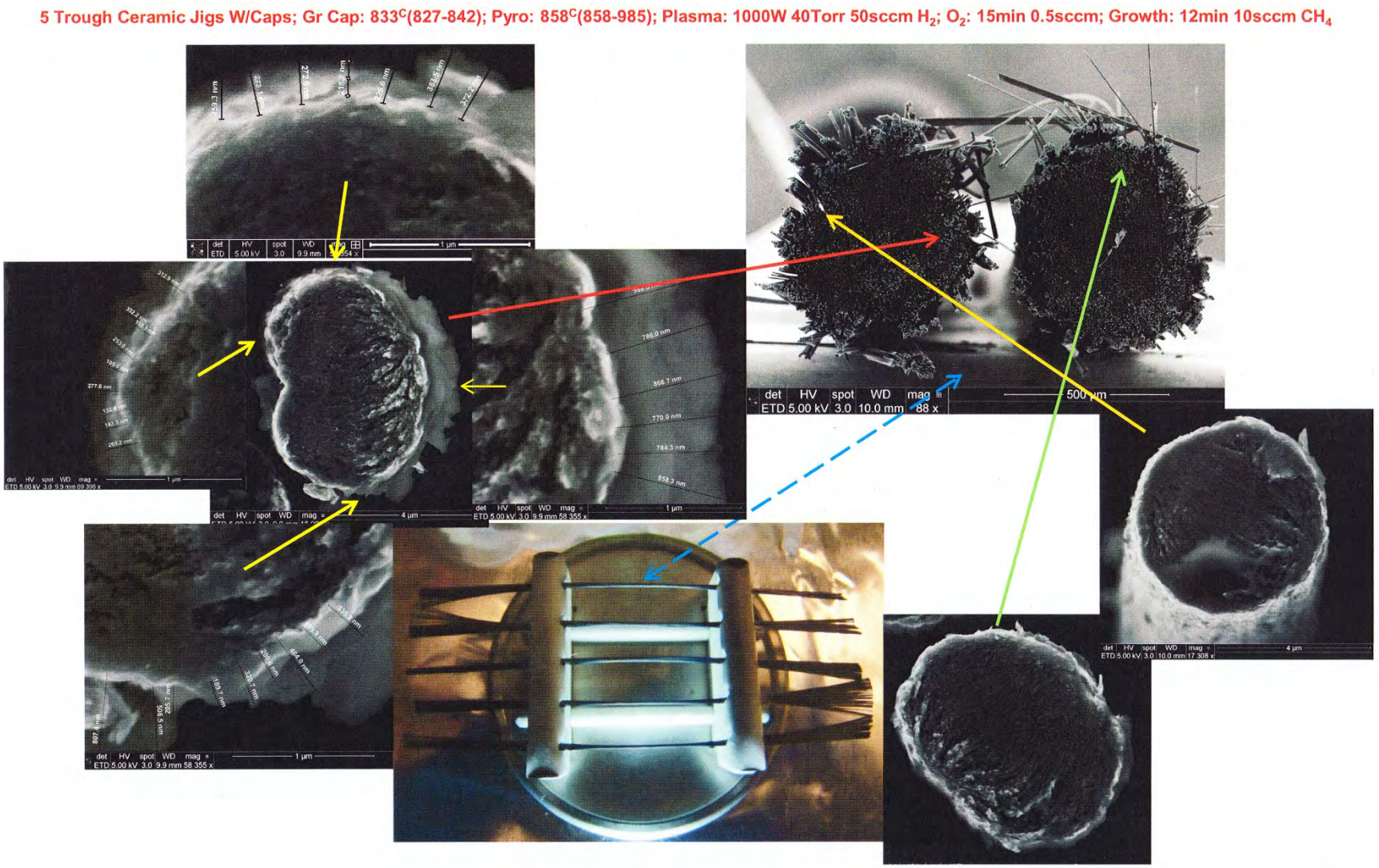


Figure FG54, M55JB Fin Growth Capped Ceramic Jig O5a Position End View

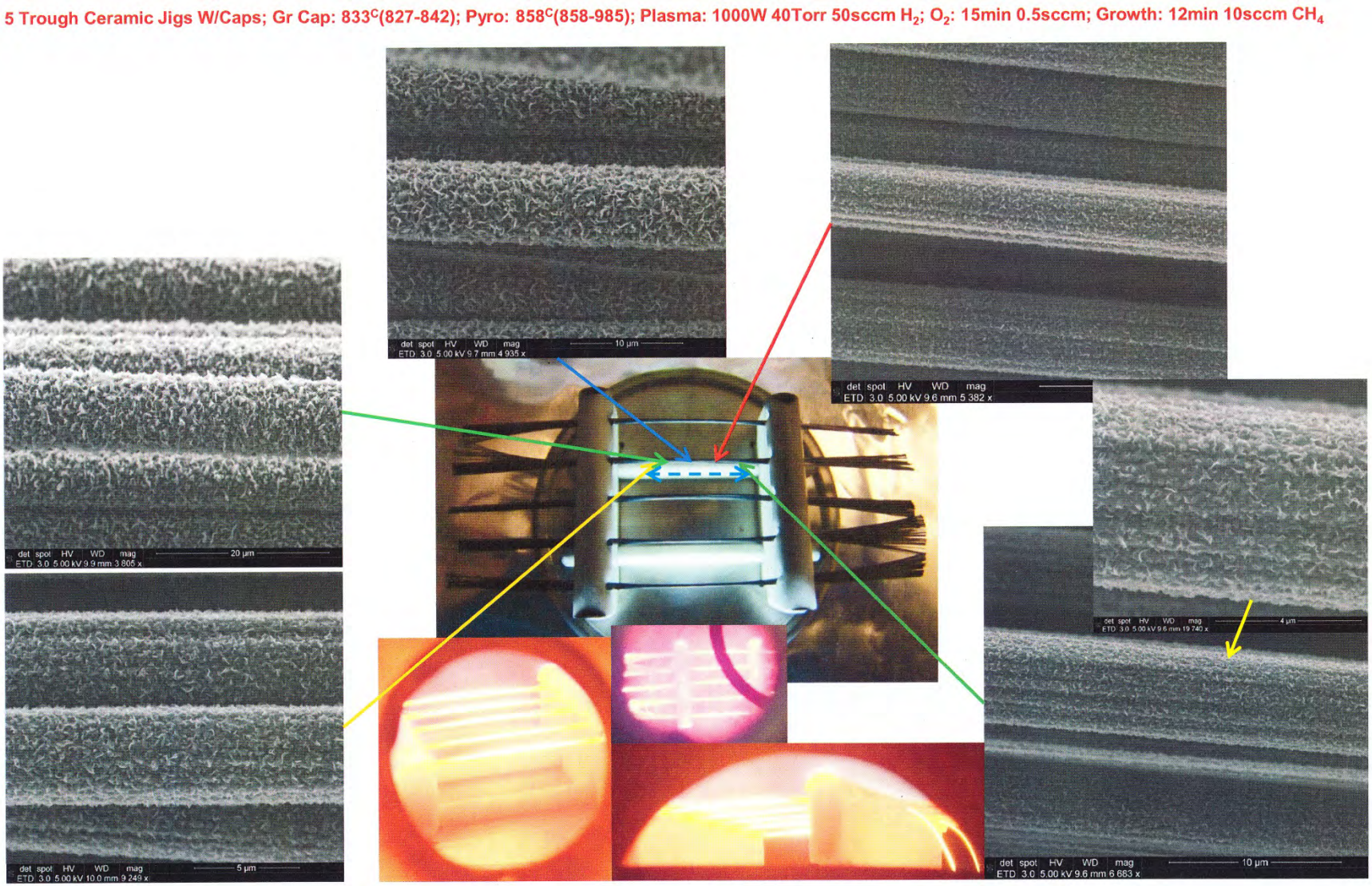


Figure FG55, M55JB Fin Growth Capped Ceramic Jig M5a Position Side View

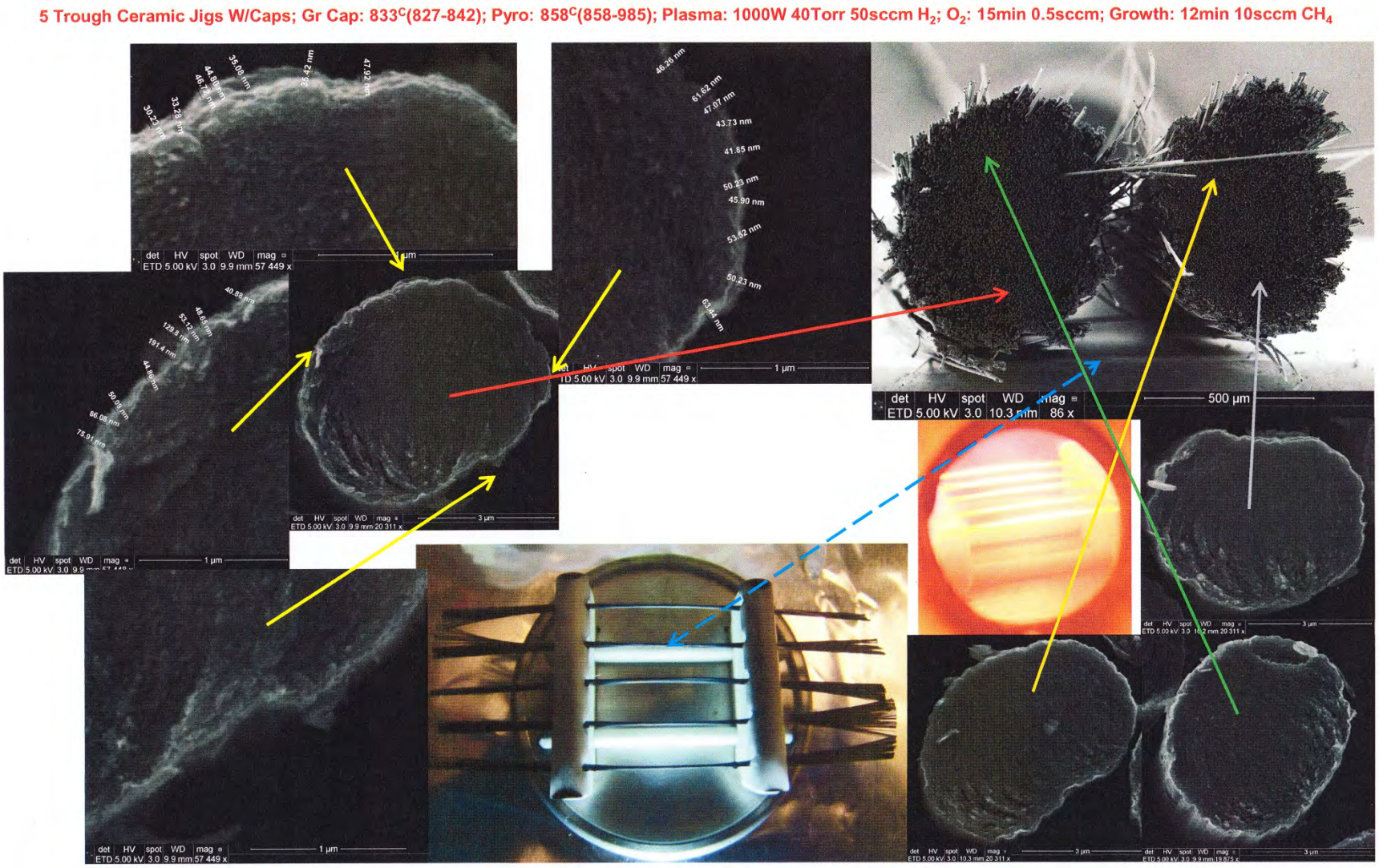


Figure FG56, M55JB Fin Growth Capped Ceramic Jig M5a Position End View

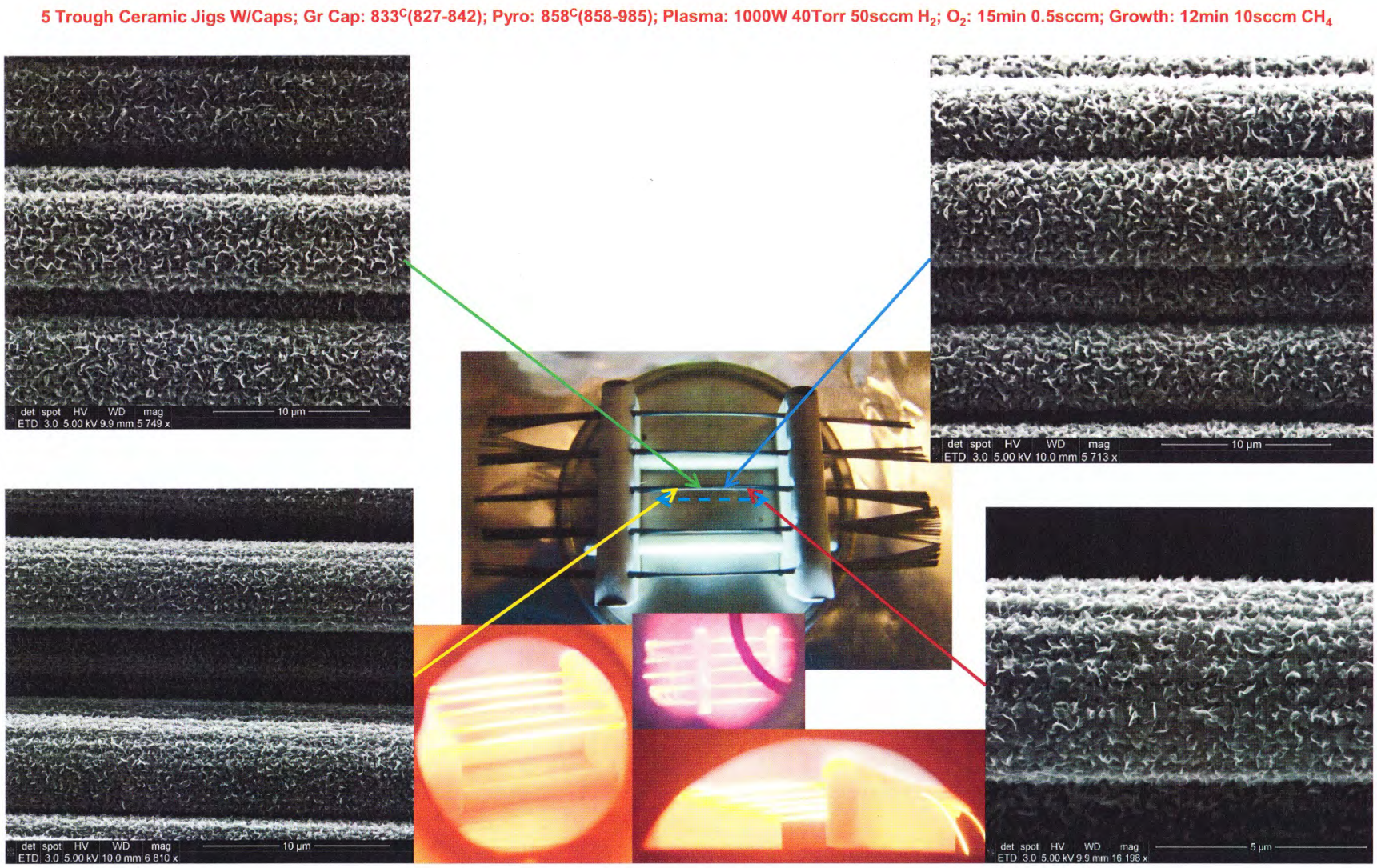


Figure FG57, M55JB Fin Growth Capped Ceramic Jig C5 Position Side View

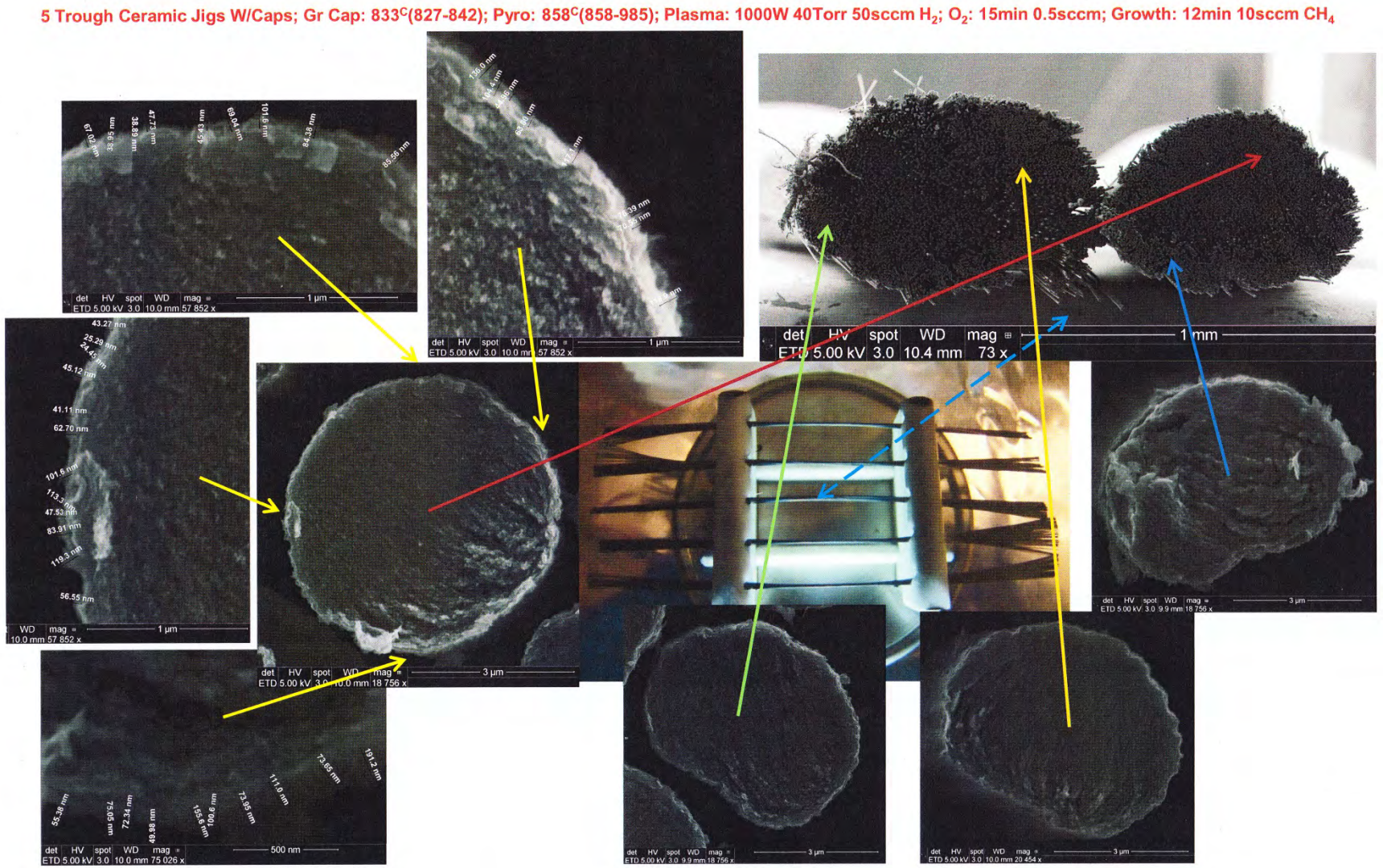


Figure FG58, M55JB Fin Growth Capped Ceramic Jig C5 Position End View

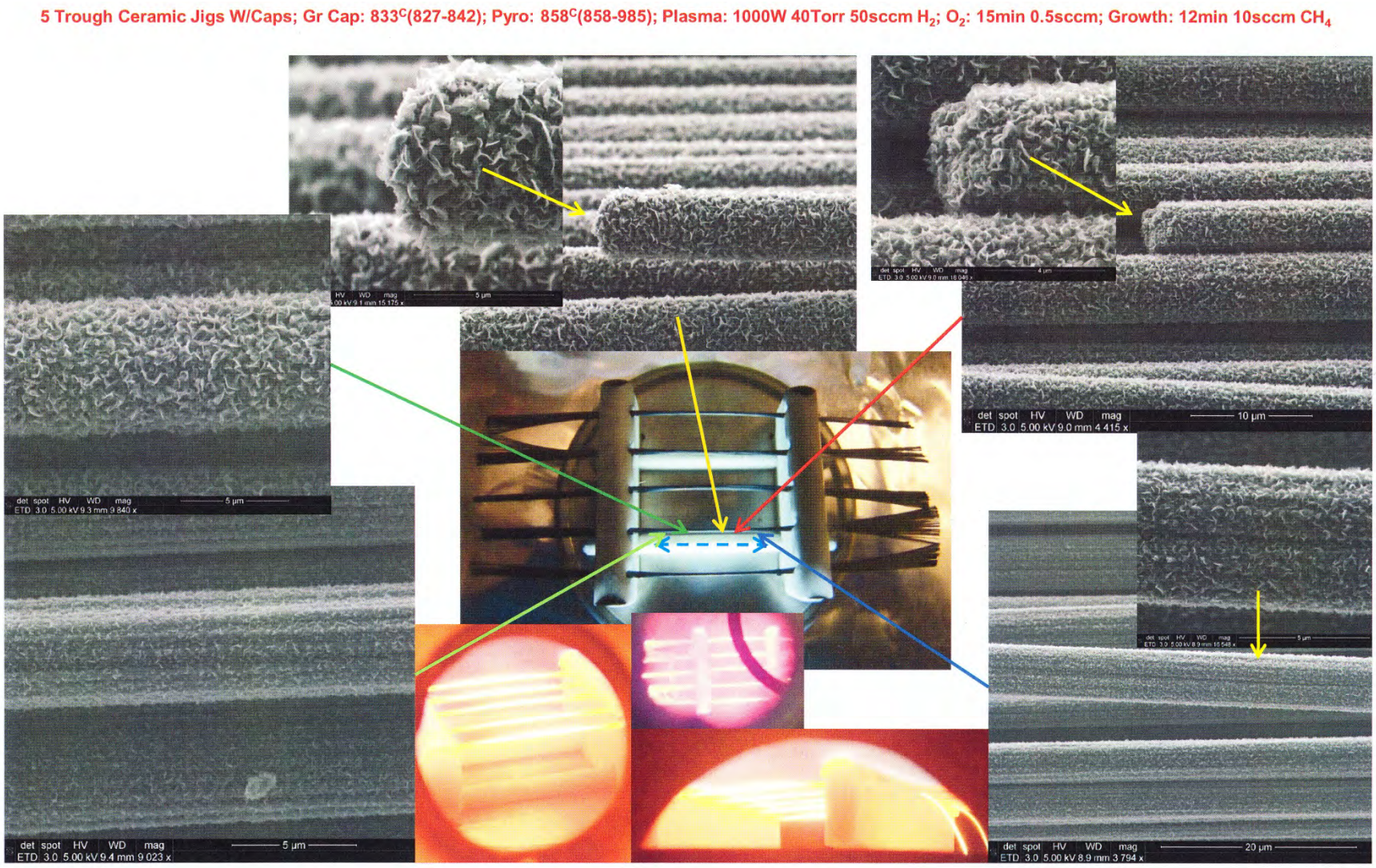


Figure FG59, M55JB Fin Growth Capped Ceramic Jig M5b Position Side View

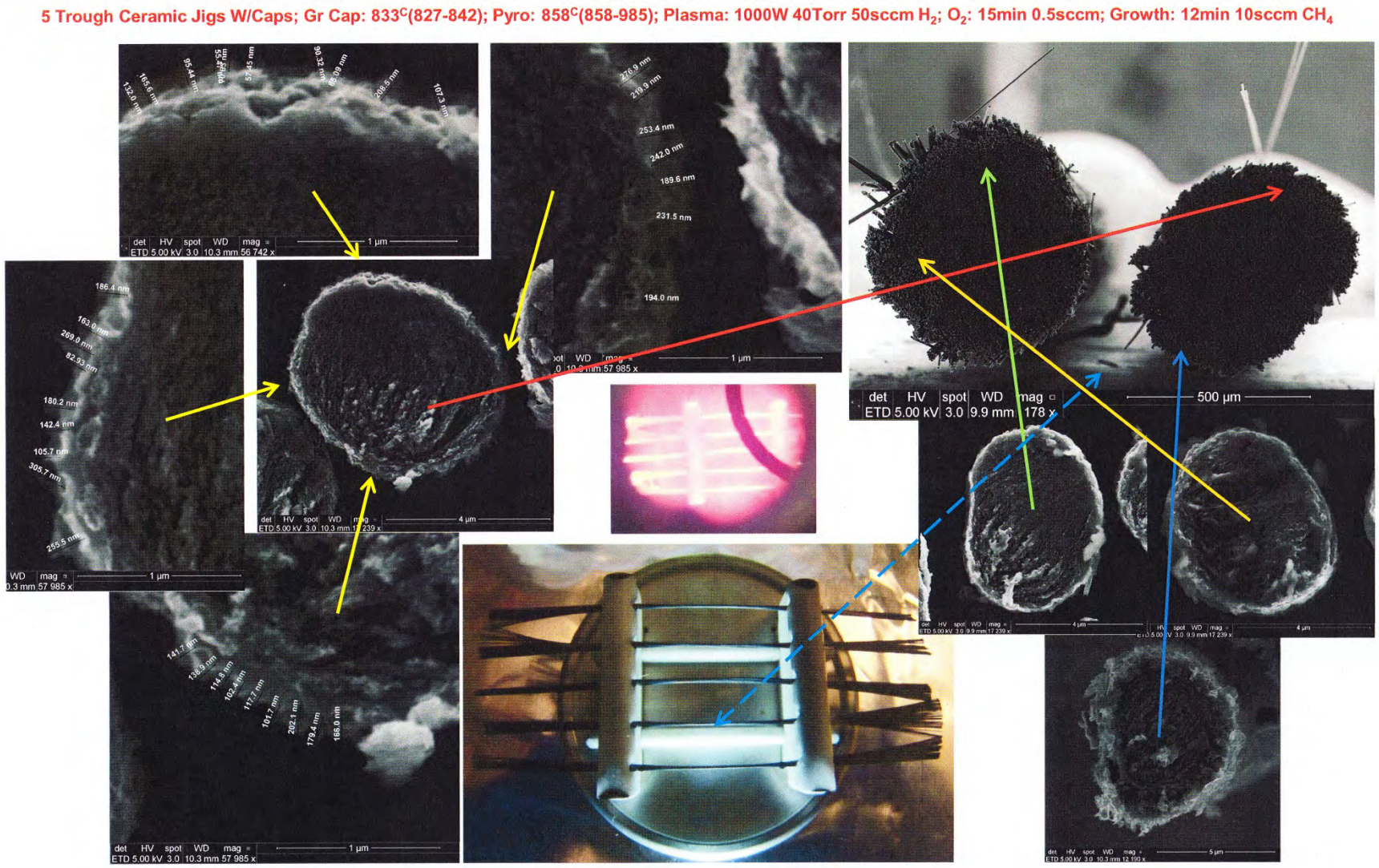


Figure FG60, M55JB Fin Growth Capped Ceramic Jig M5b Position End View

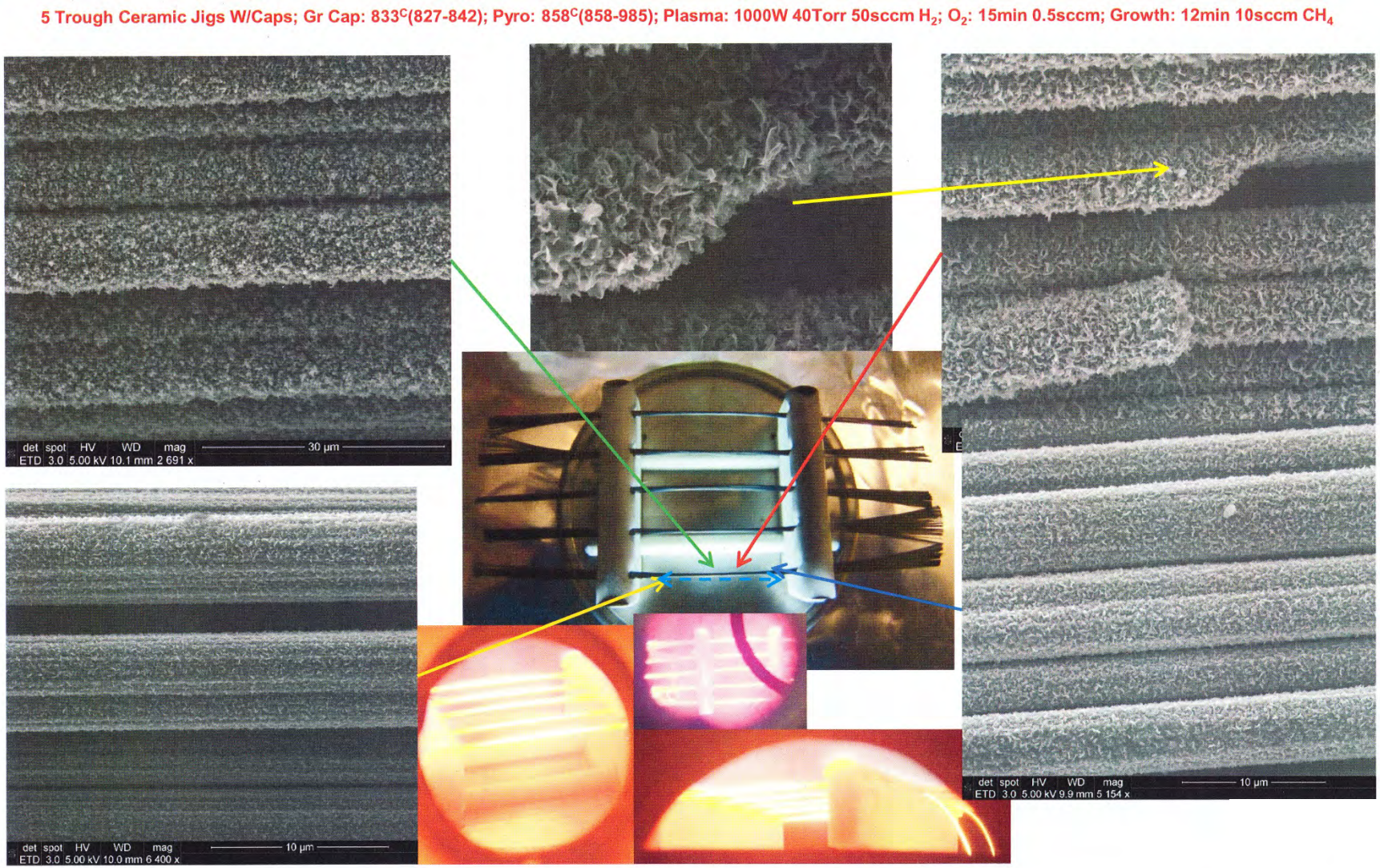


Figure FG61, M55JB Fin Growth Capped Ceramic Jig O5b Position Side View

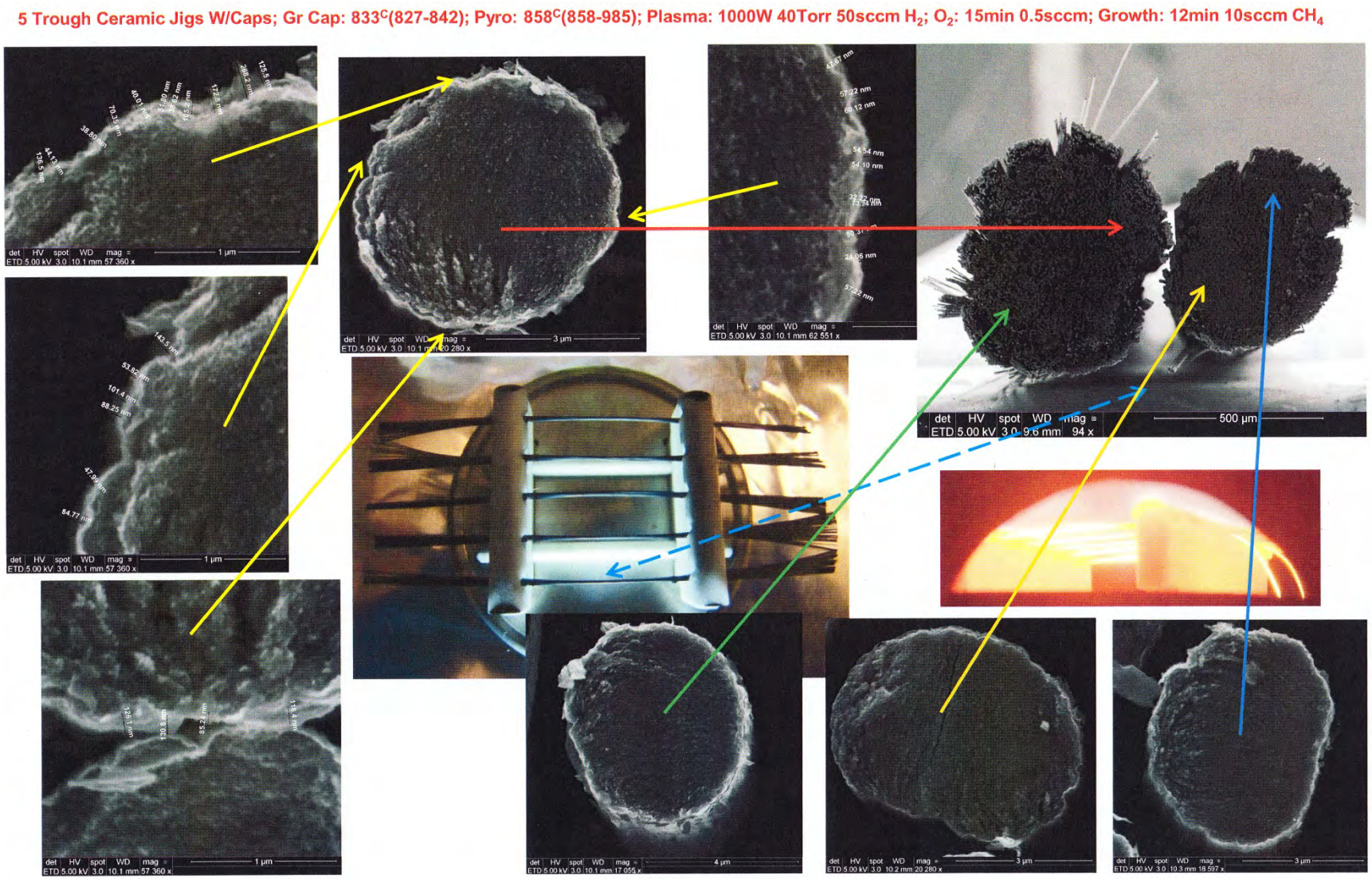


Figure FG62, M55JB Fin Growth Capped Ceramic Jig O5b Position End View

3.10 Section 10: YSH60A Fin Growth

Use: Outer 3 on one side of 5 trough Ceramic Jigs; Gr Cap: 867C; Pyro: 886C; O2: Last 5 min of growth 0.5sccm; Plasma: 1000W 40Torr 50sccm H2; Growth: 15min 10sccm CH4

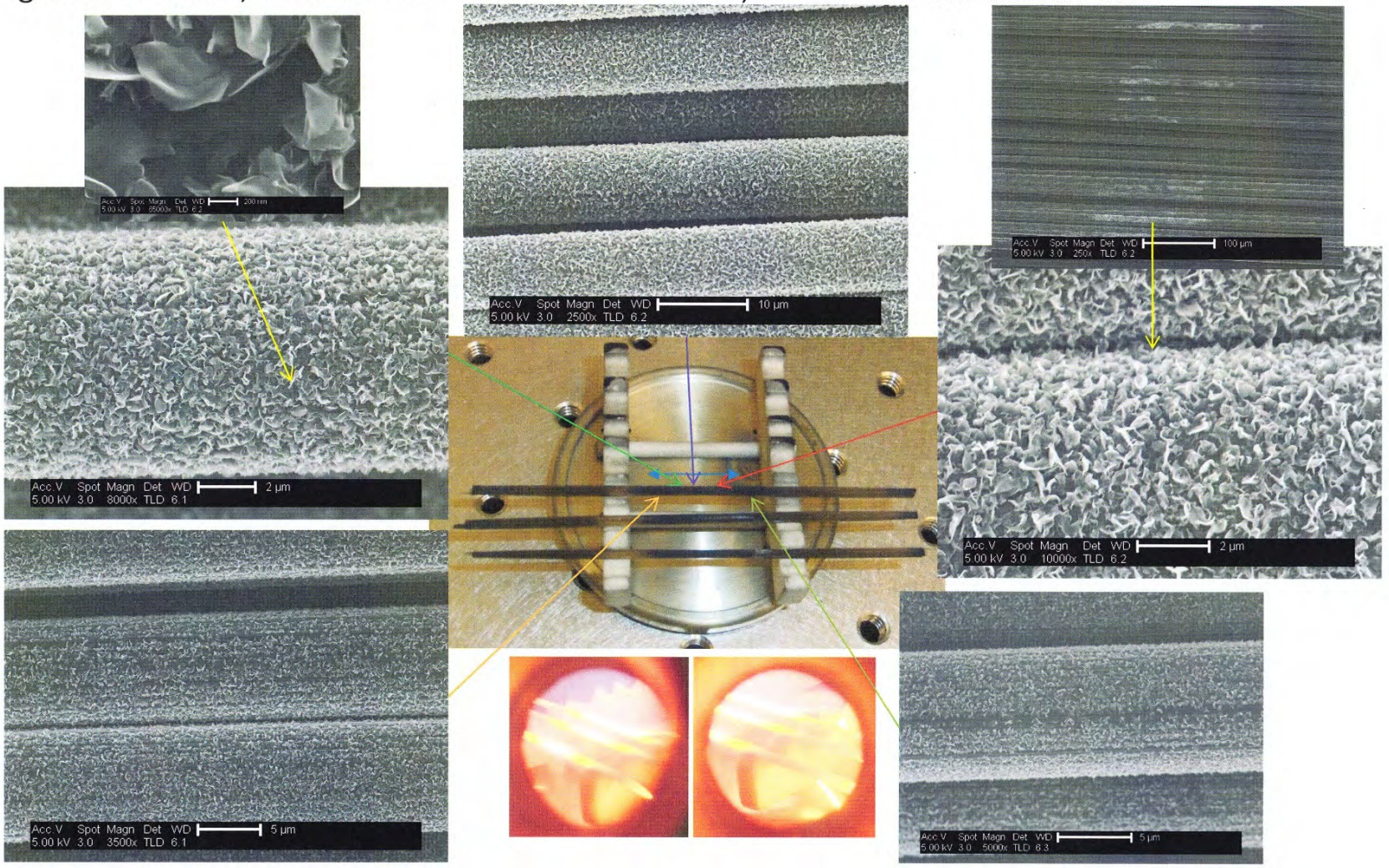


Figure FG63, YSH60A Fin Growth Ceramic Jig IM7 Position Side View

Use: Outer 3 on one side of 5 trough Ceramic Jigs; Gr Cap: 867C; Pyro: 886C; O2: Last 5 min of growth 0.5sccm; Plasma: 1000W 40Torr 50sccm H2; Growth: 15min 10sccm CH4

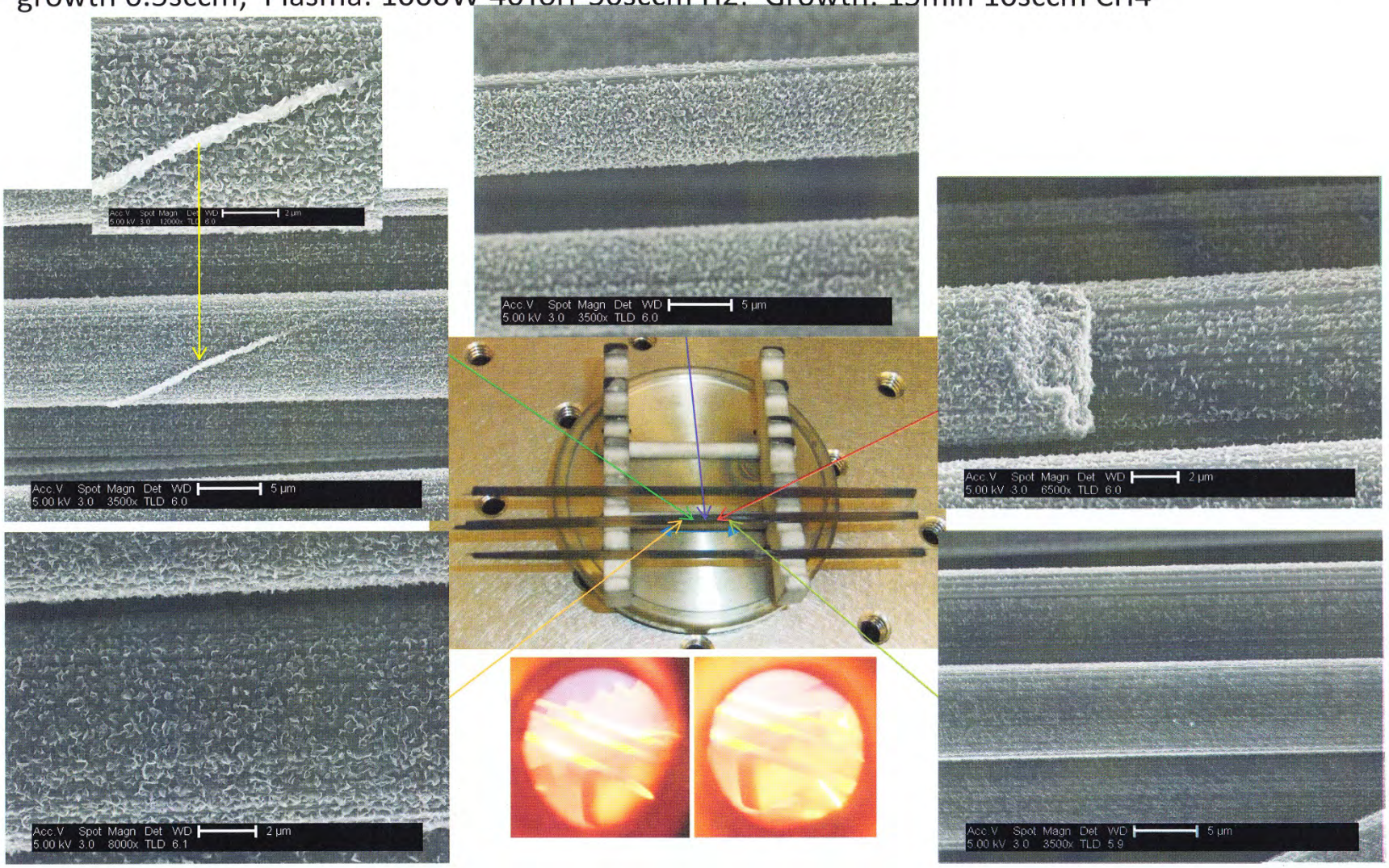


Figure FG64, YSH60A Fin Growth Ceramic Jig OM7 Position Side View

Use: Outer 3 on one side of 5 trough Ceramic Jigs; Gr Cap: 867C; Pyro: 886C; O2: Last 5 min of growth 0.5sccm; Plasma: 1000W 40Torr 50sccm H2; Growth: 15min 10sccm CH4

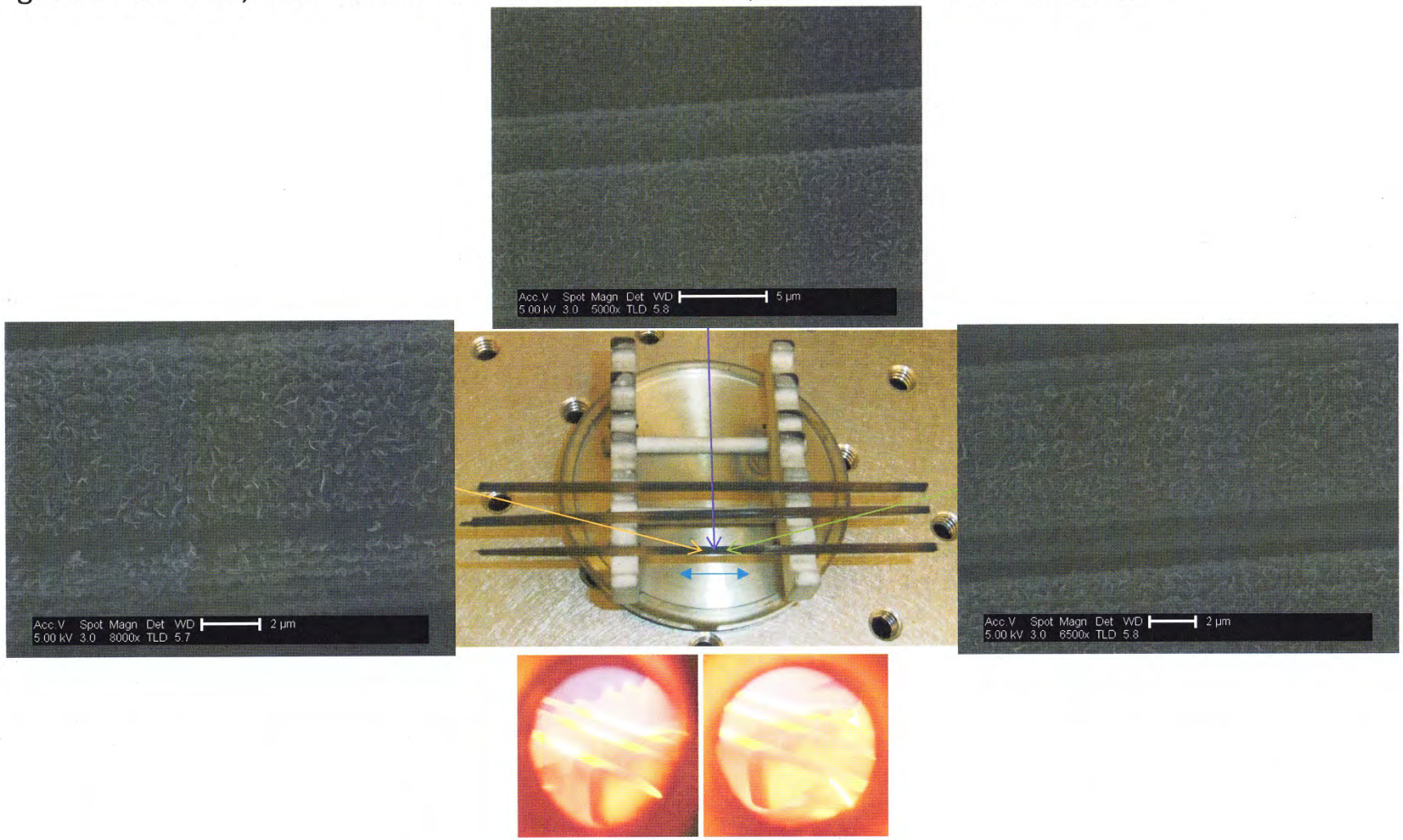


Figure FG65, YSH60A Fin Growth Ceramic Jig O7 Position Side View

3.11 Section 11: YS80A Fin Growth

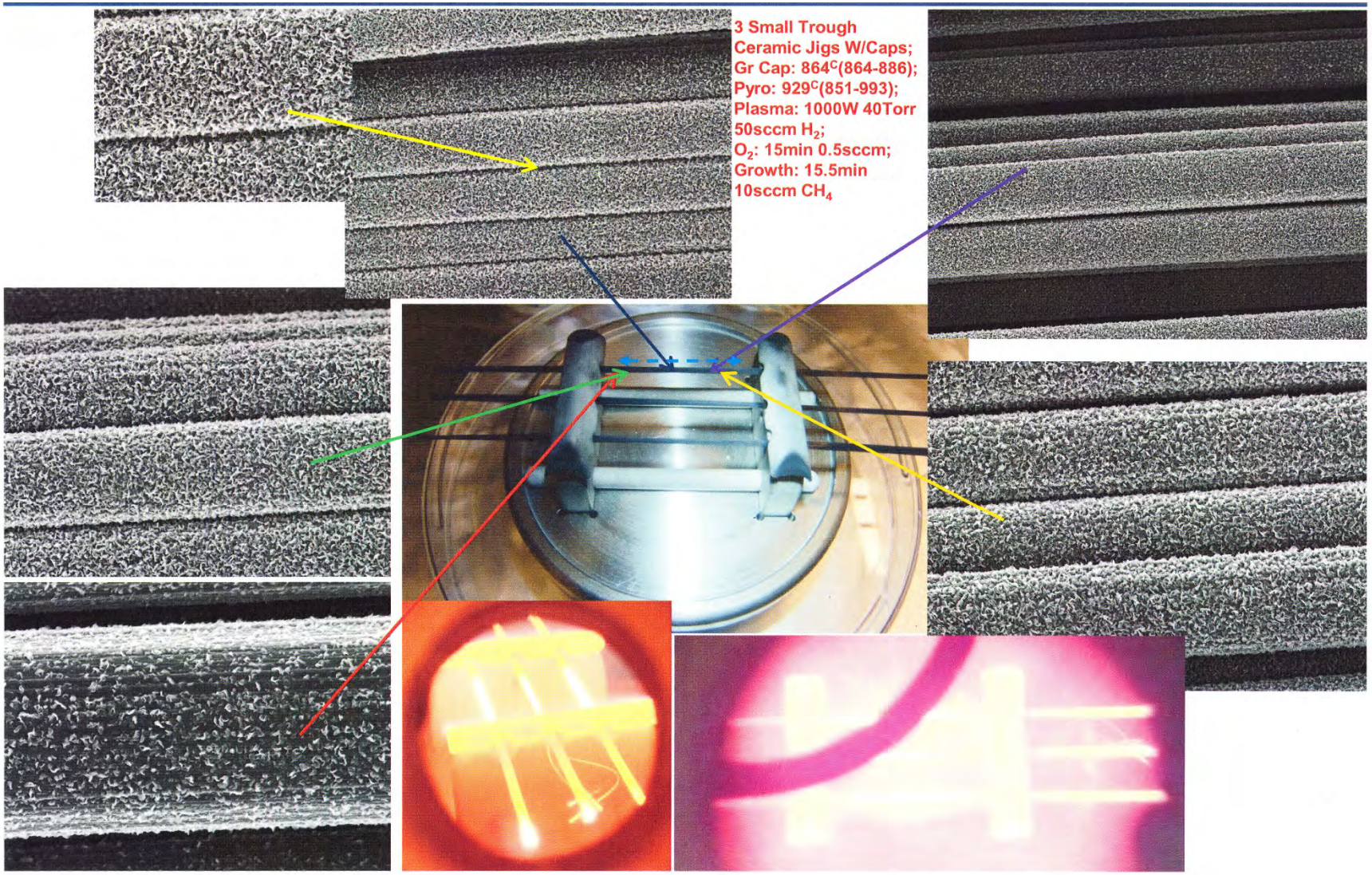


Figure FG66, YS80A Fin Growth Capped Ceramic Jig O3a Position Surface View

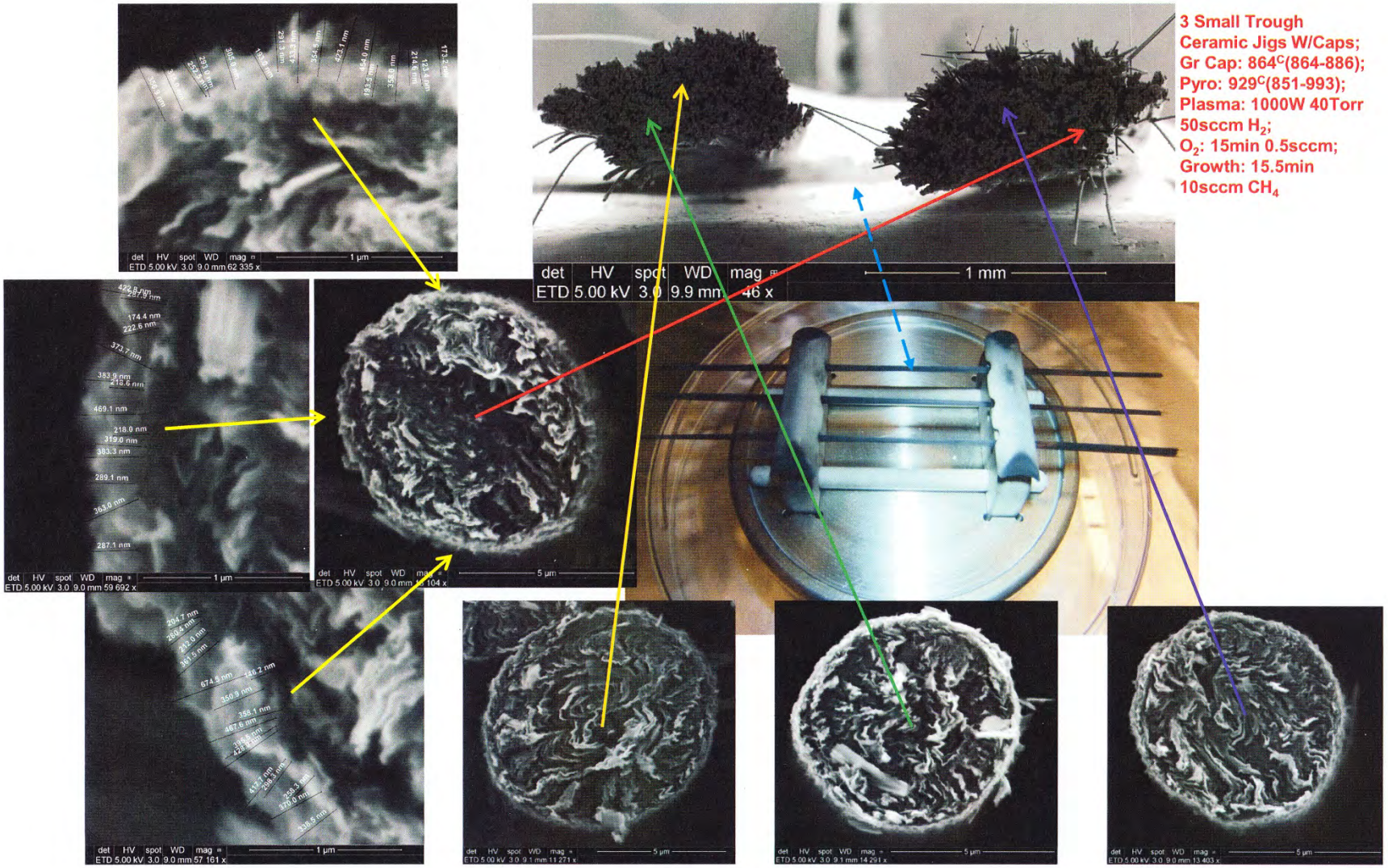


Figure FG67, YS80A Fin Growth Capped Ceramic Jig O3a Position End View

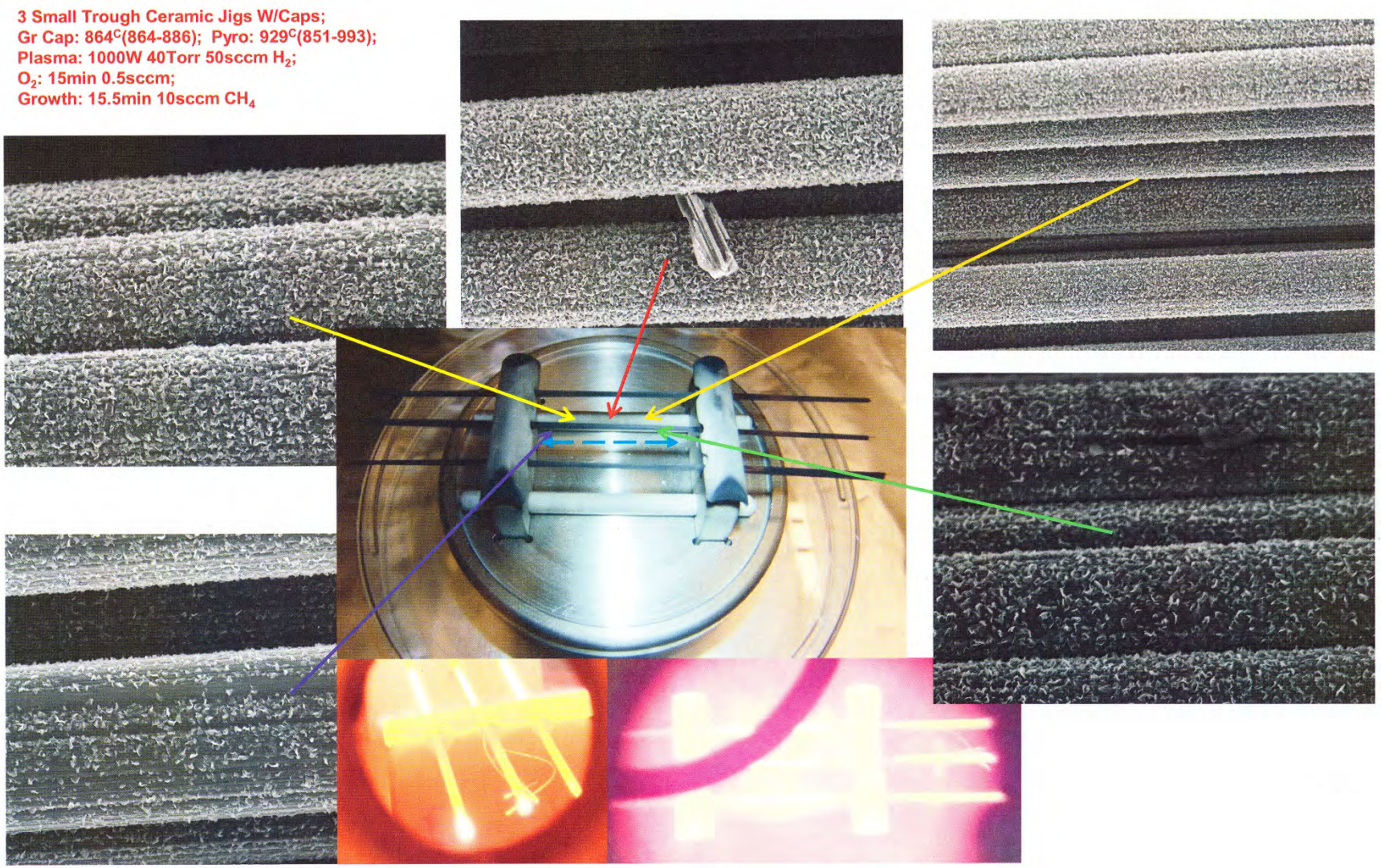


Figure FG68, YS80A Fin Growth Capped Ceramic Jig C3 Position Surface View

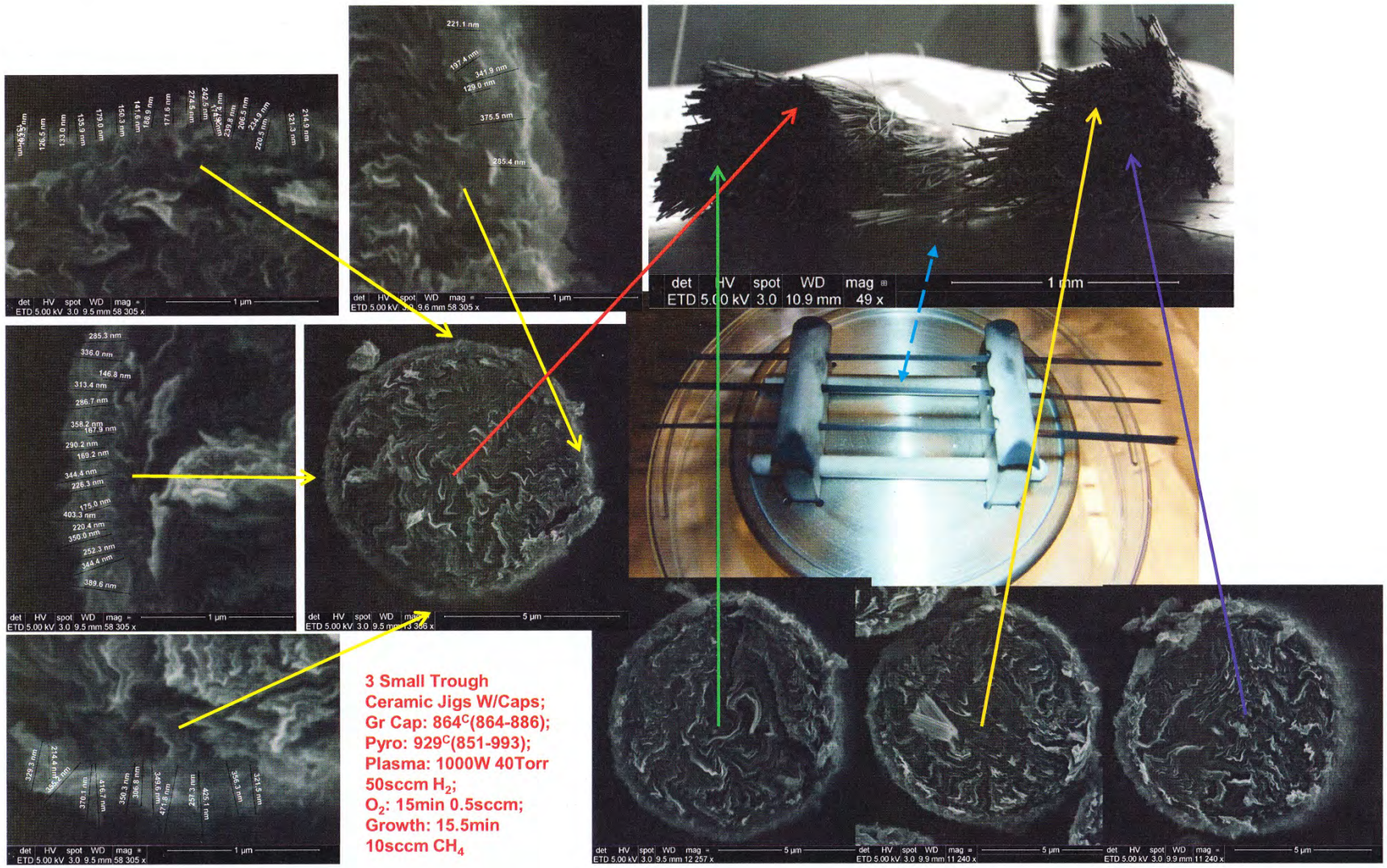


Figure FG69, YS80A Fin Growth Capped Ceramic Jig C3 Position Surface View

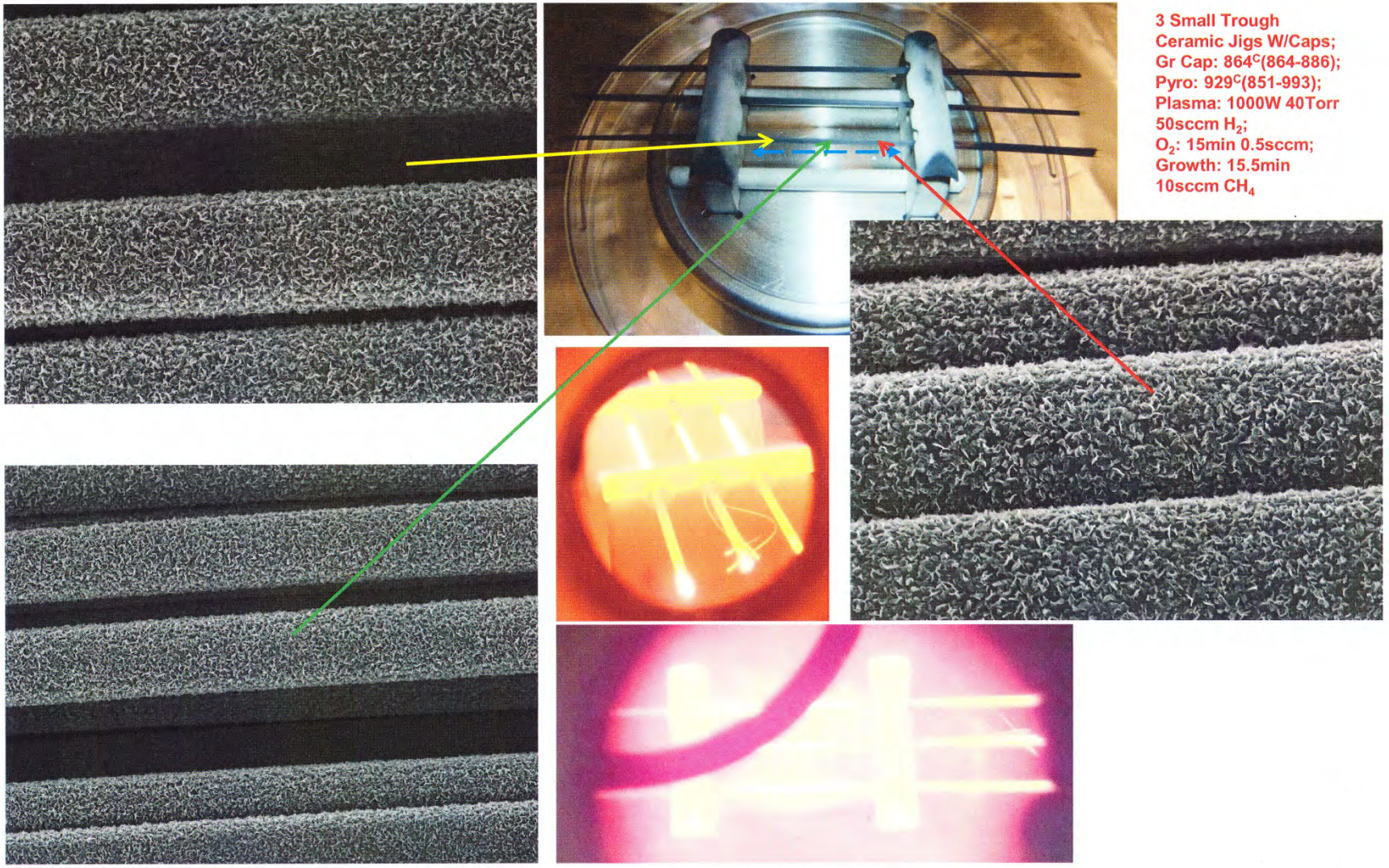


Figure FG70, YS80A Fin Growth Capped Ceramic Jig O3b Position Surface View

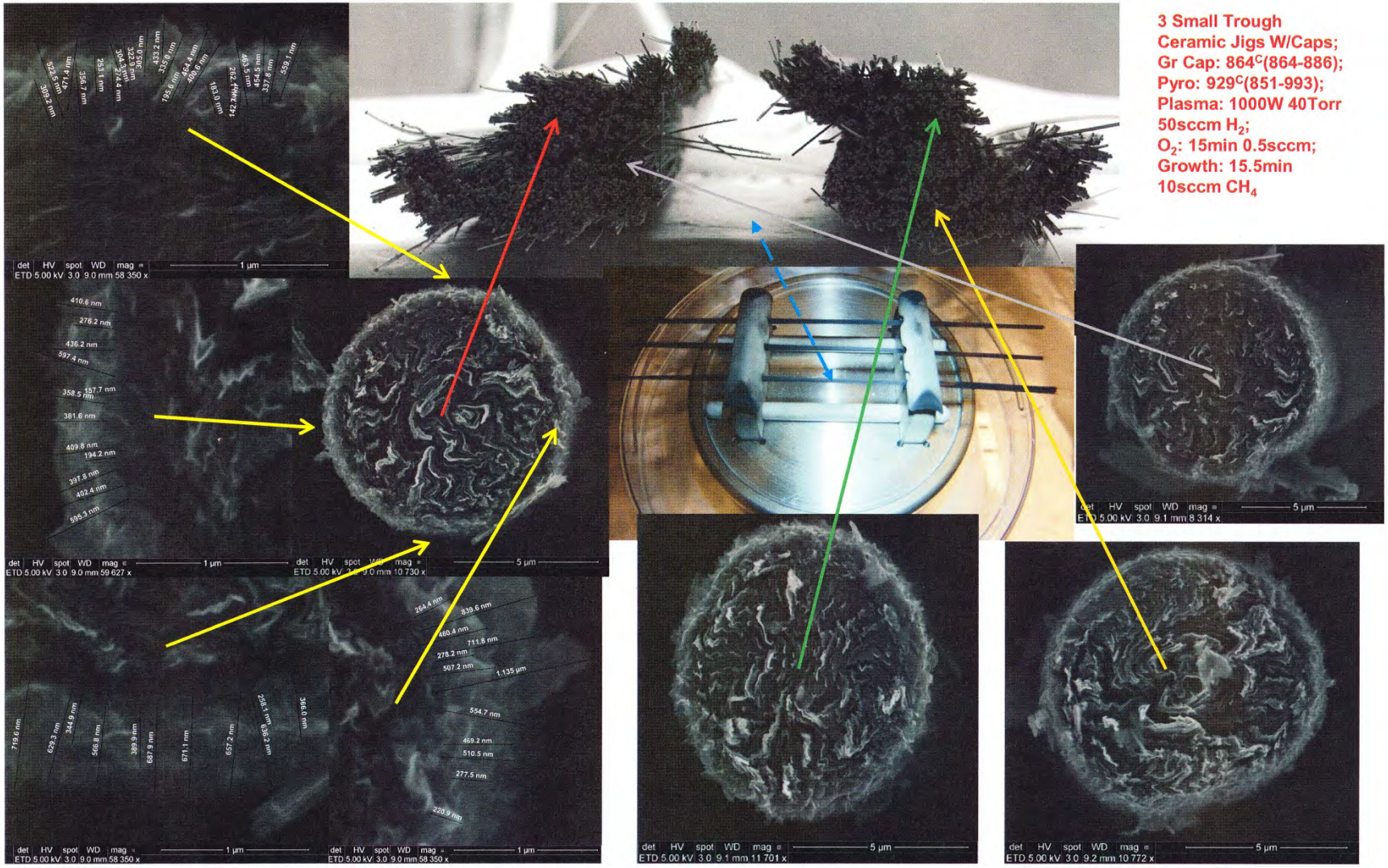


Figure FG71, YS80A Fin Growth Capped Ceramic Jig O3b Position End View

3.12.1 Section 12-1: P100S 7 Un Capped Tow Fin Growth

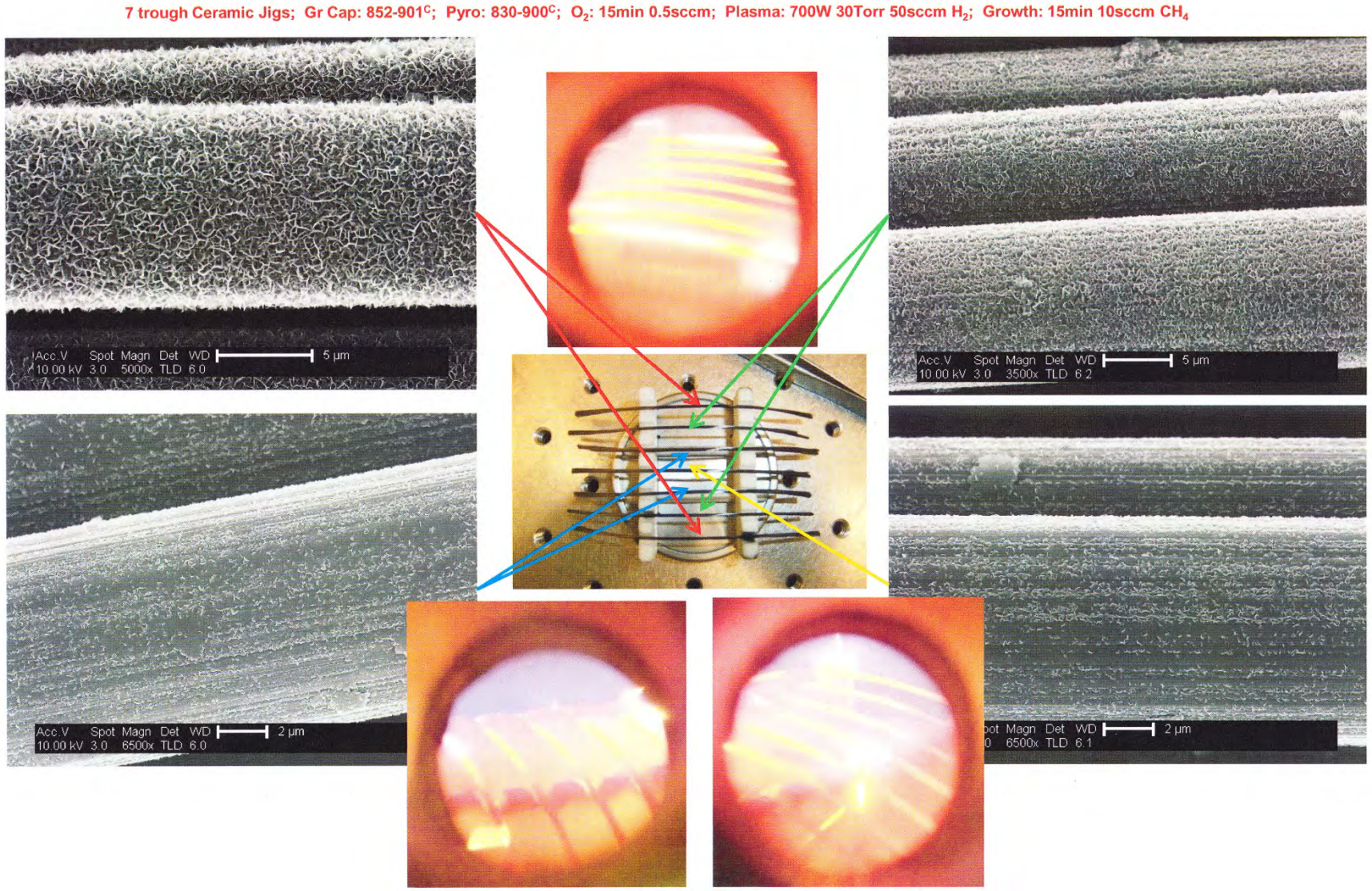


Figure FG72, P100S 7 Tow Fin Growth 7 Tow Ceramic Jig Various Jig Positions Surface View

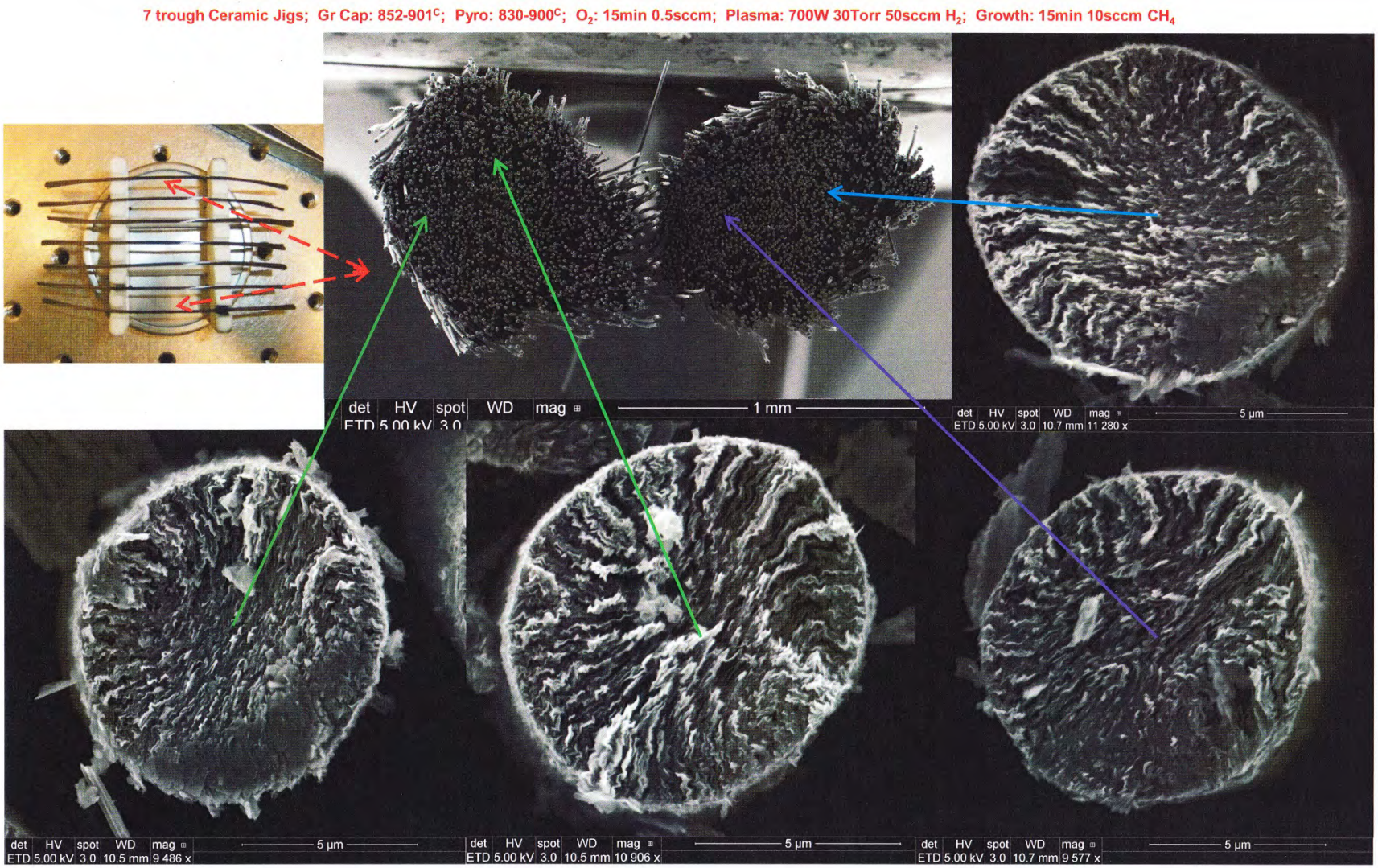


Figure FG73, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig O7 Positions End View I

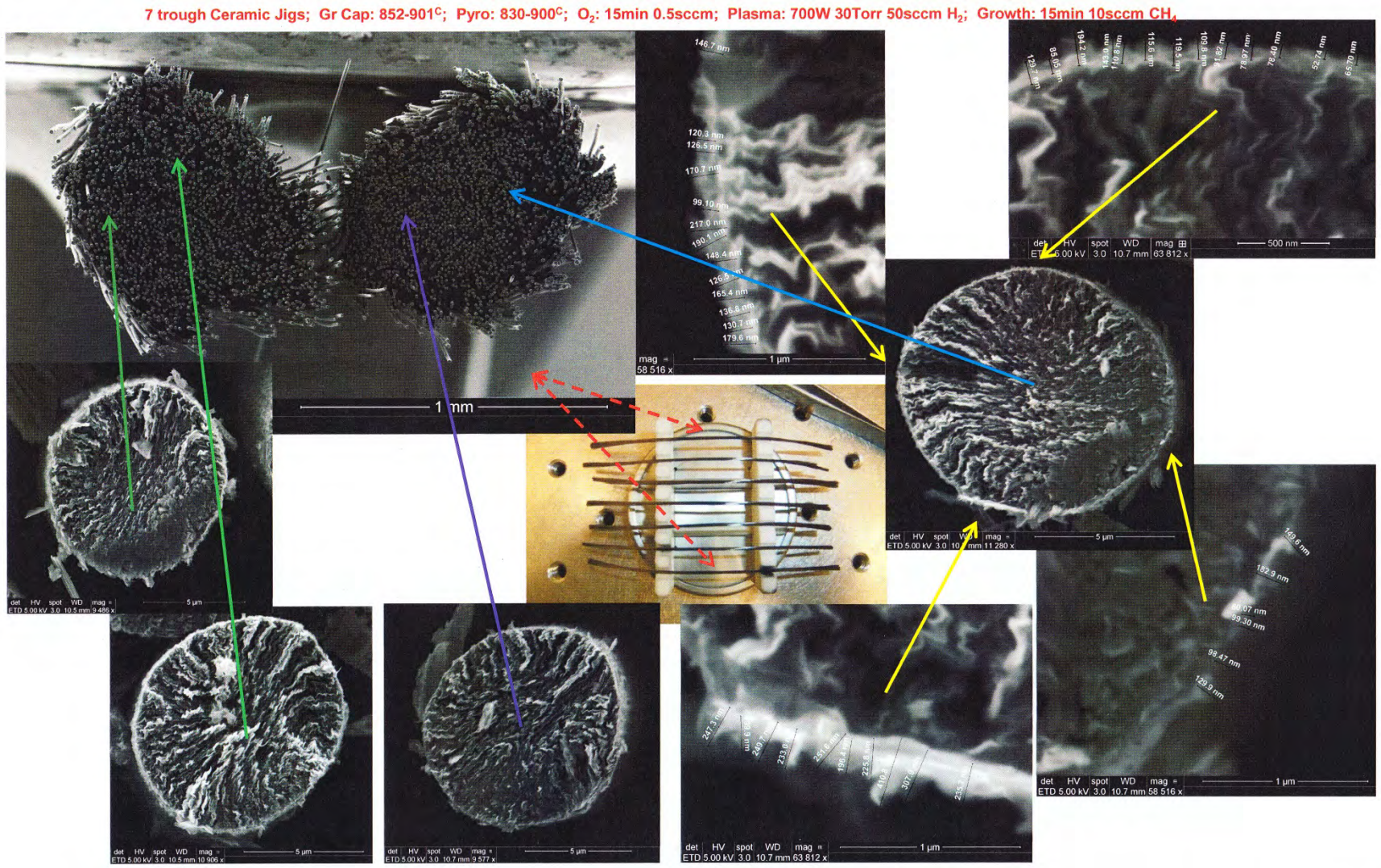


Figure FG74, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig O7 Positions End View II

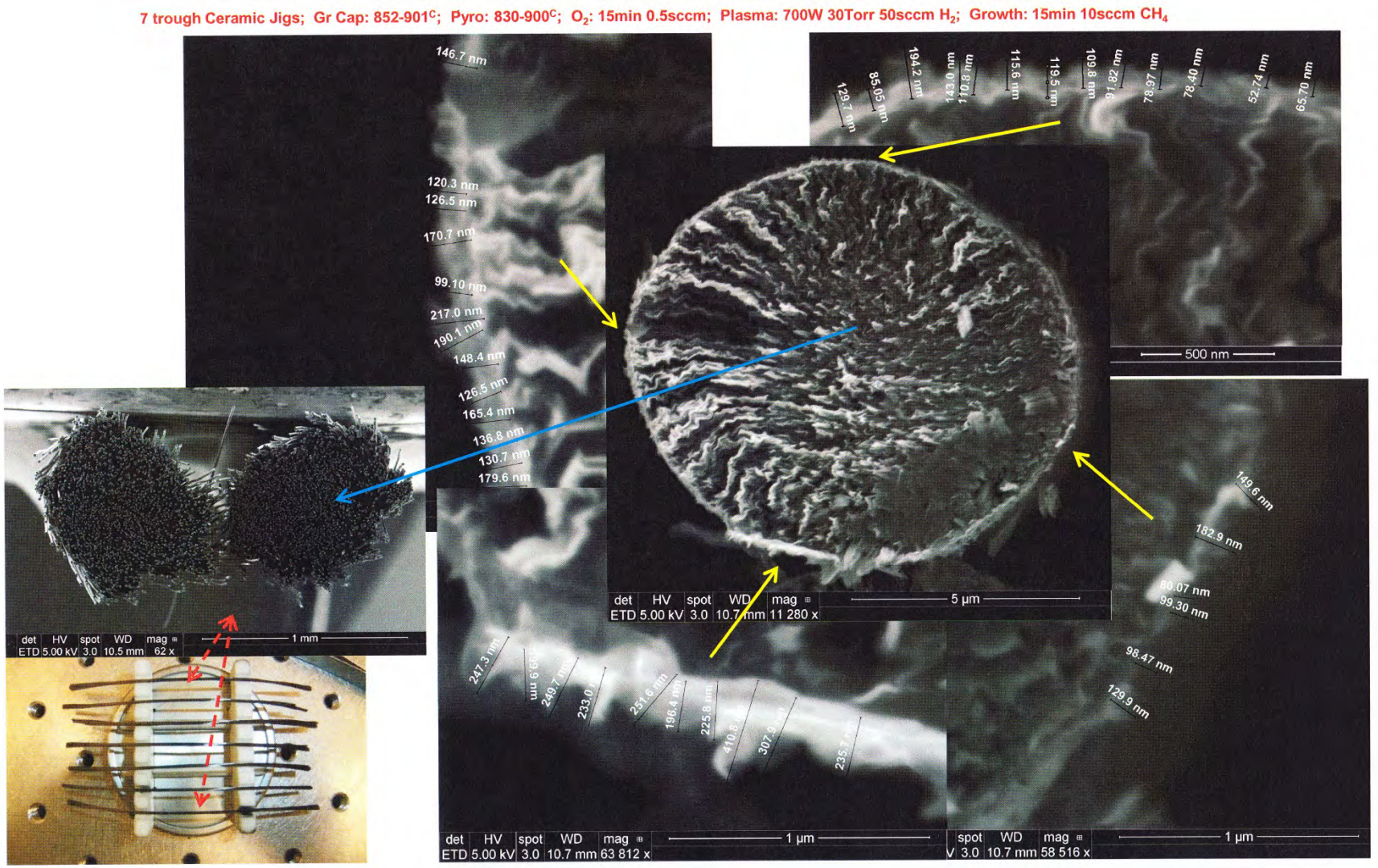


Figure FG75, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig O7 Positions End View III

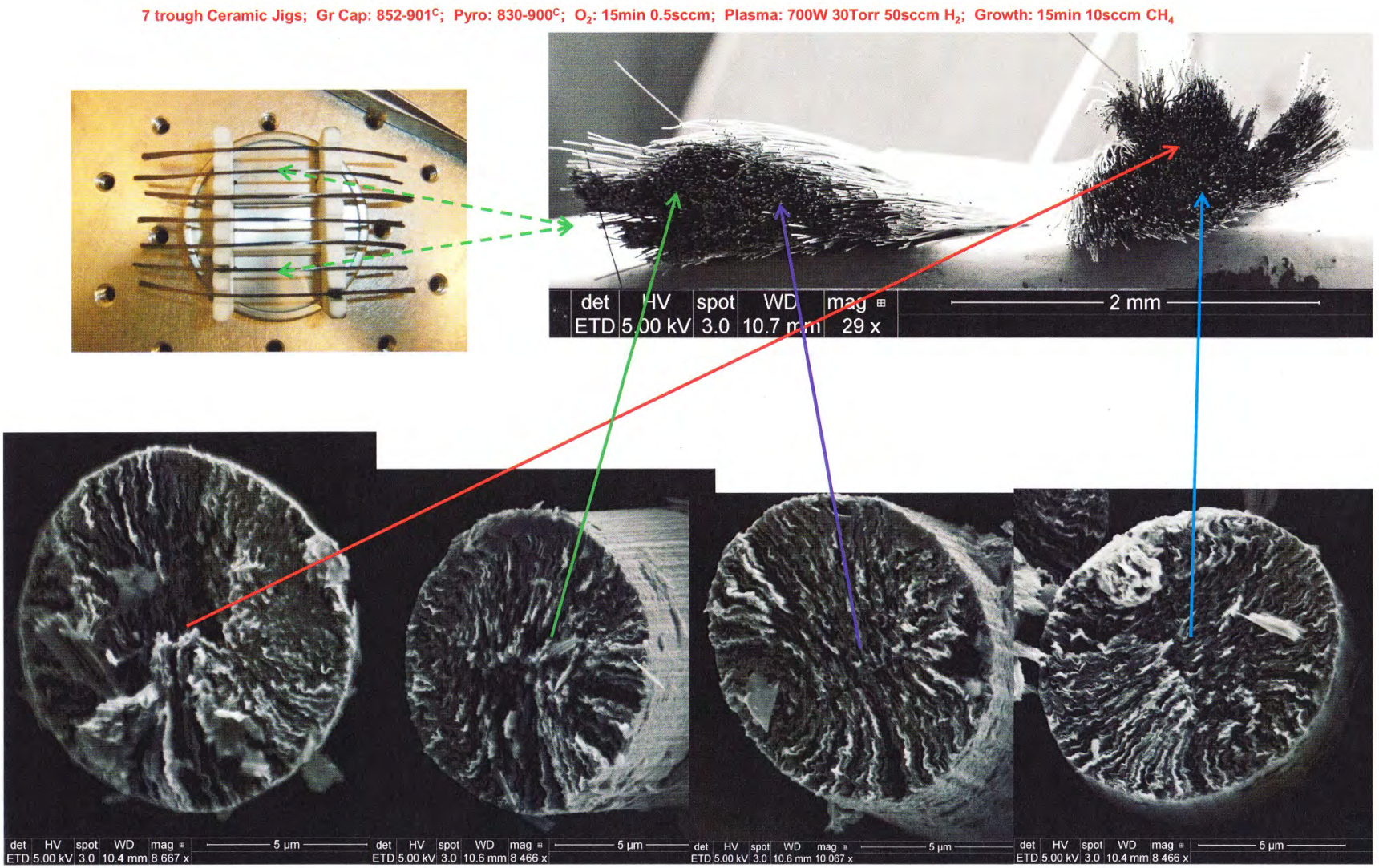


Figure FG76, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig OM7a Positions End View I

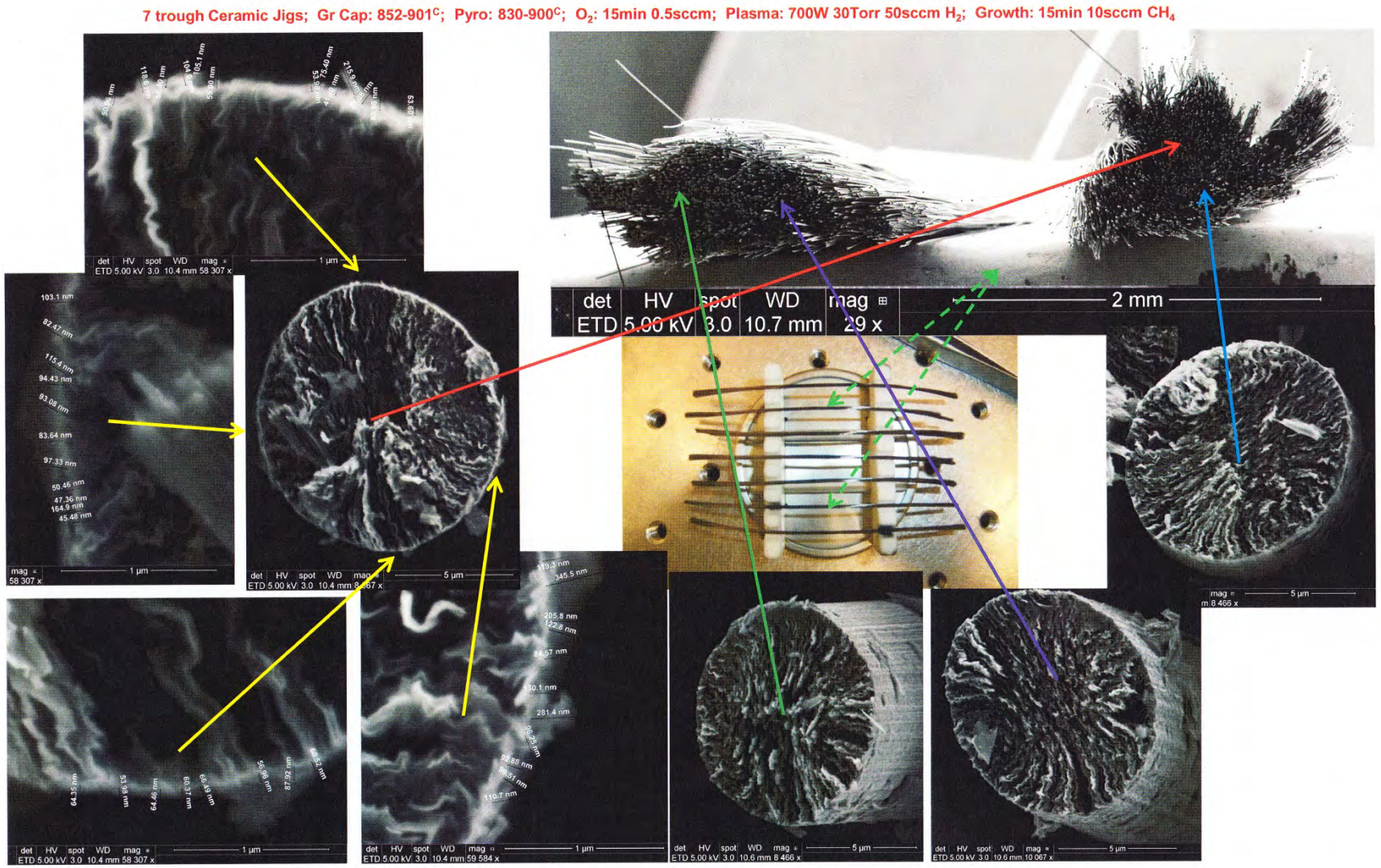


Figure FG77, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig OM7a Positions End View II

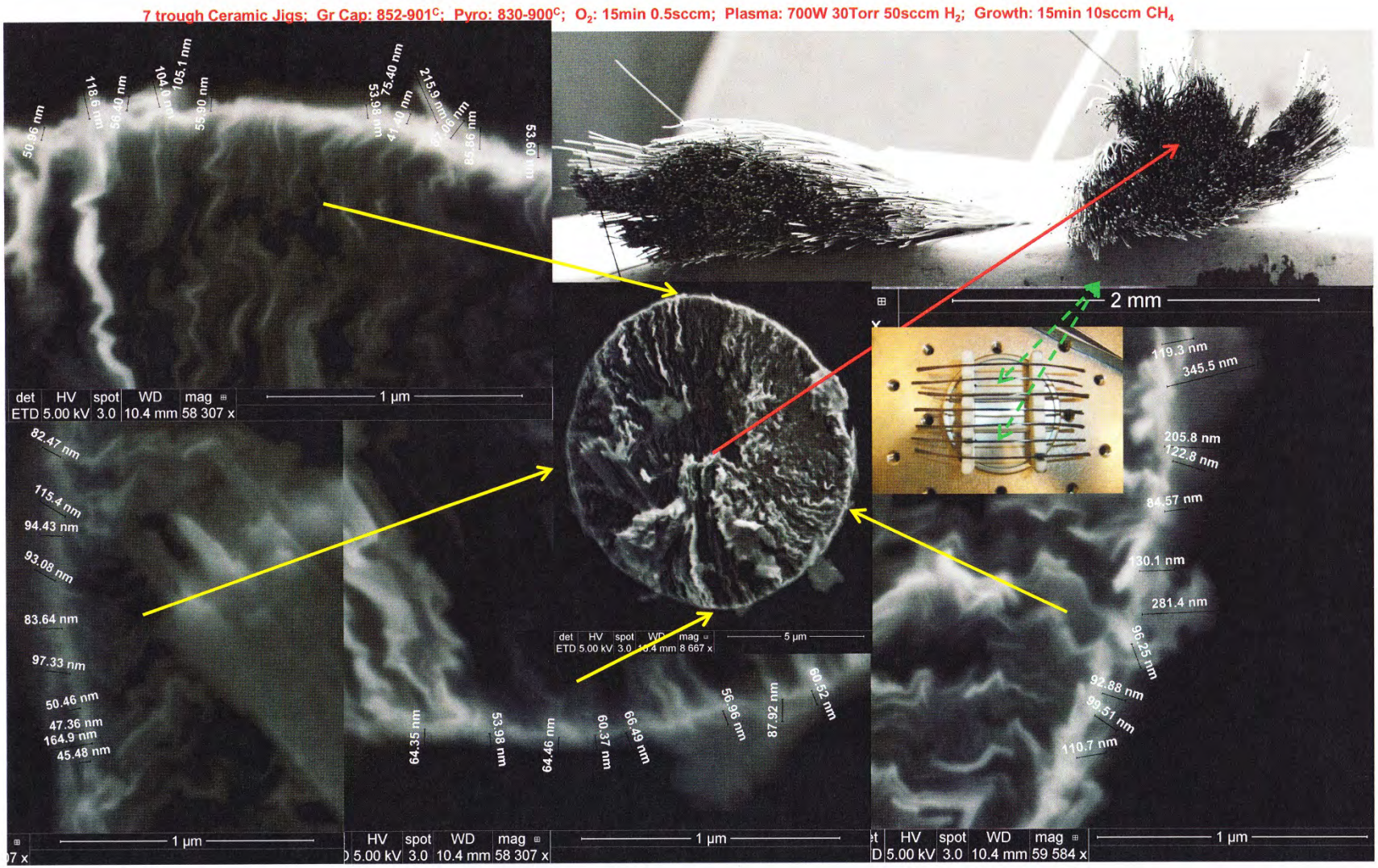


Figure FG78, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig OM7a Positions End View III

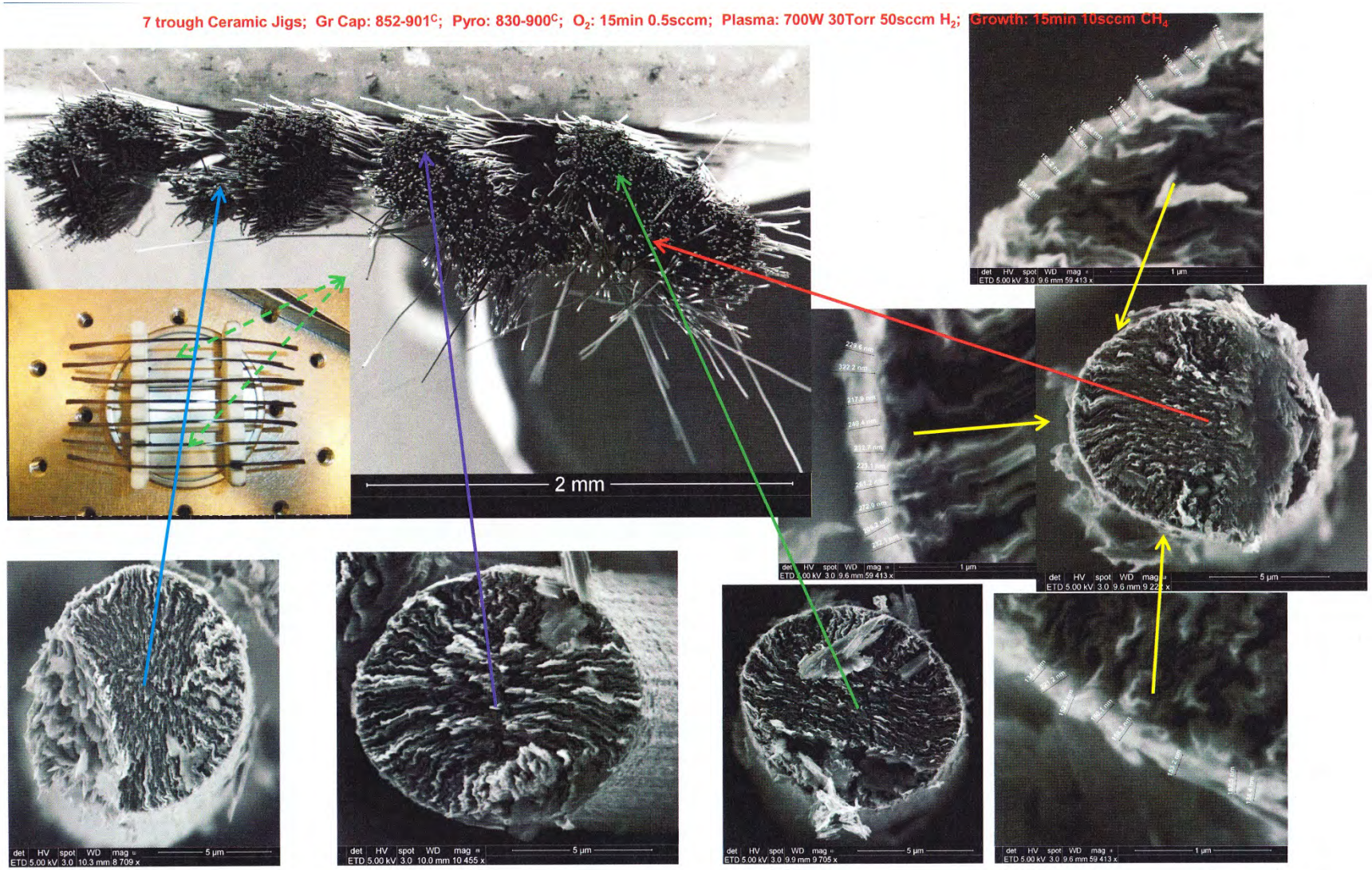


Figure FG79, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig OM7b Positions End View

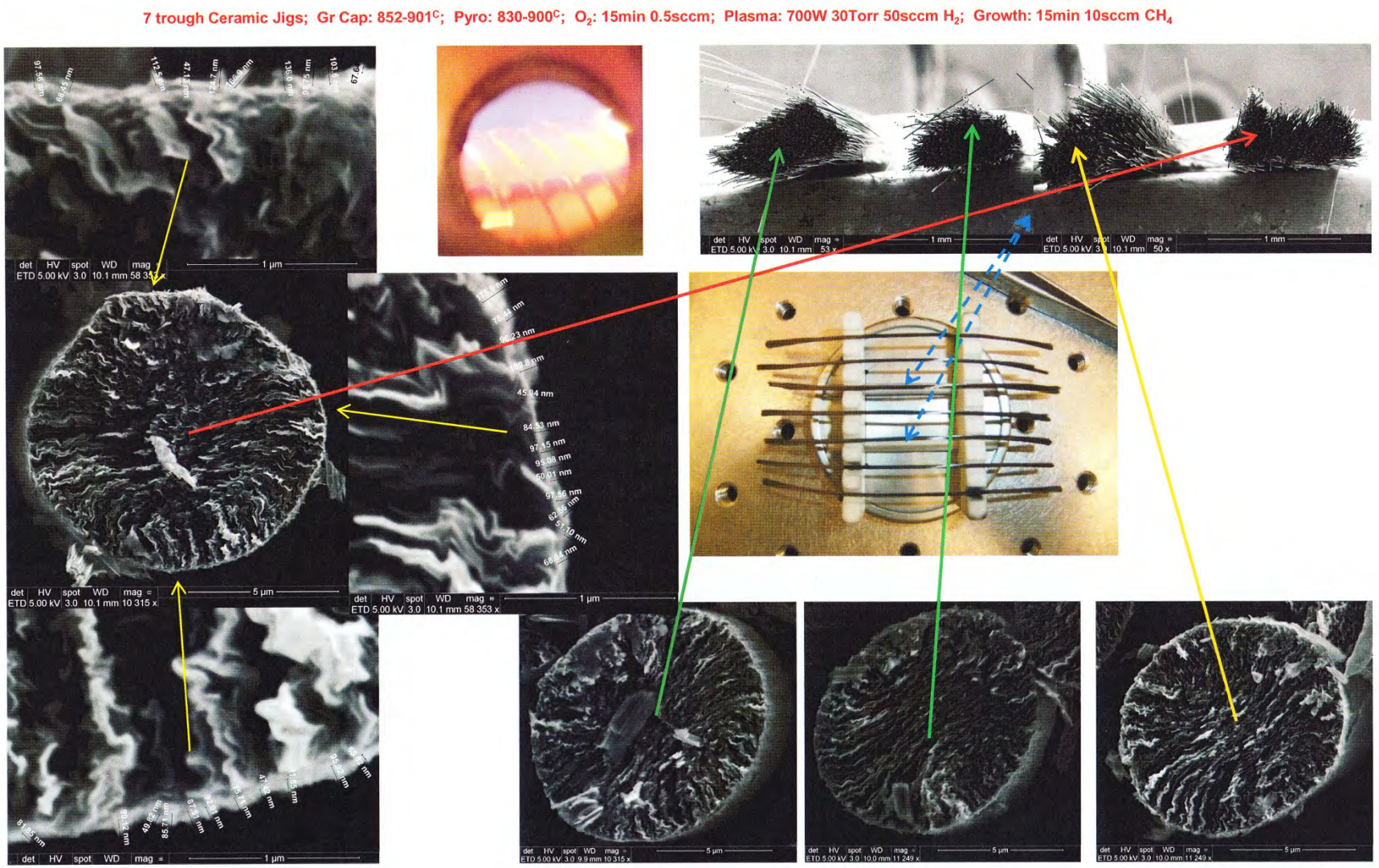


Figure FG80, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig IM7A Positions End View

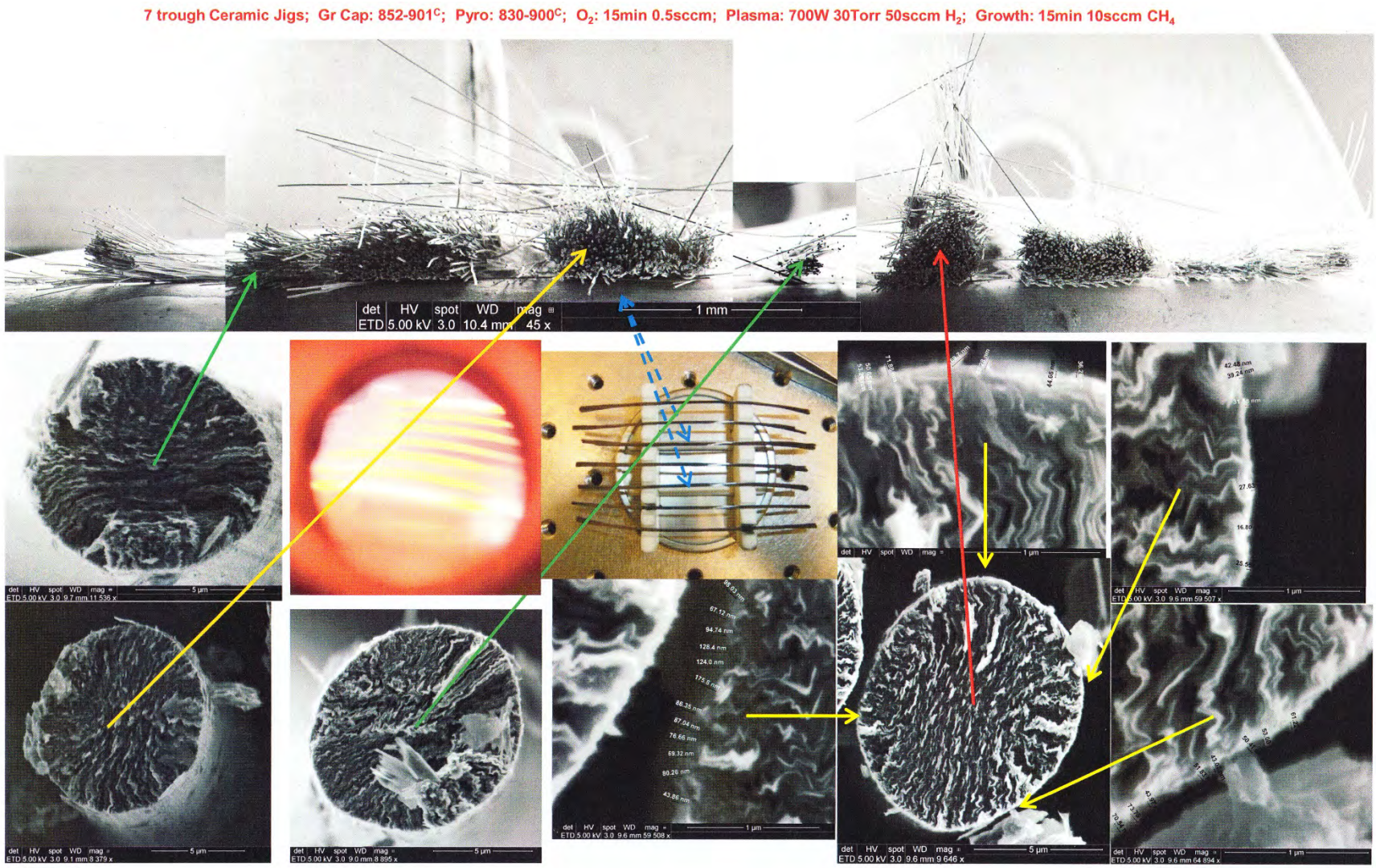


Figure FG81, P100S 7 Tow Fin Growth 7 Tow Un Capped Ceramic Jig IM7b Positions End View

3.12.2 Section 12-2: P100S 5 Un Capped Tow Fin Growth

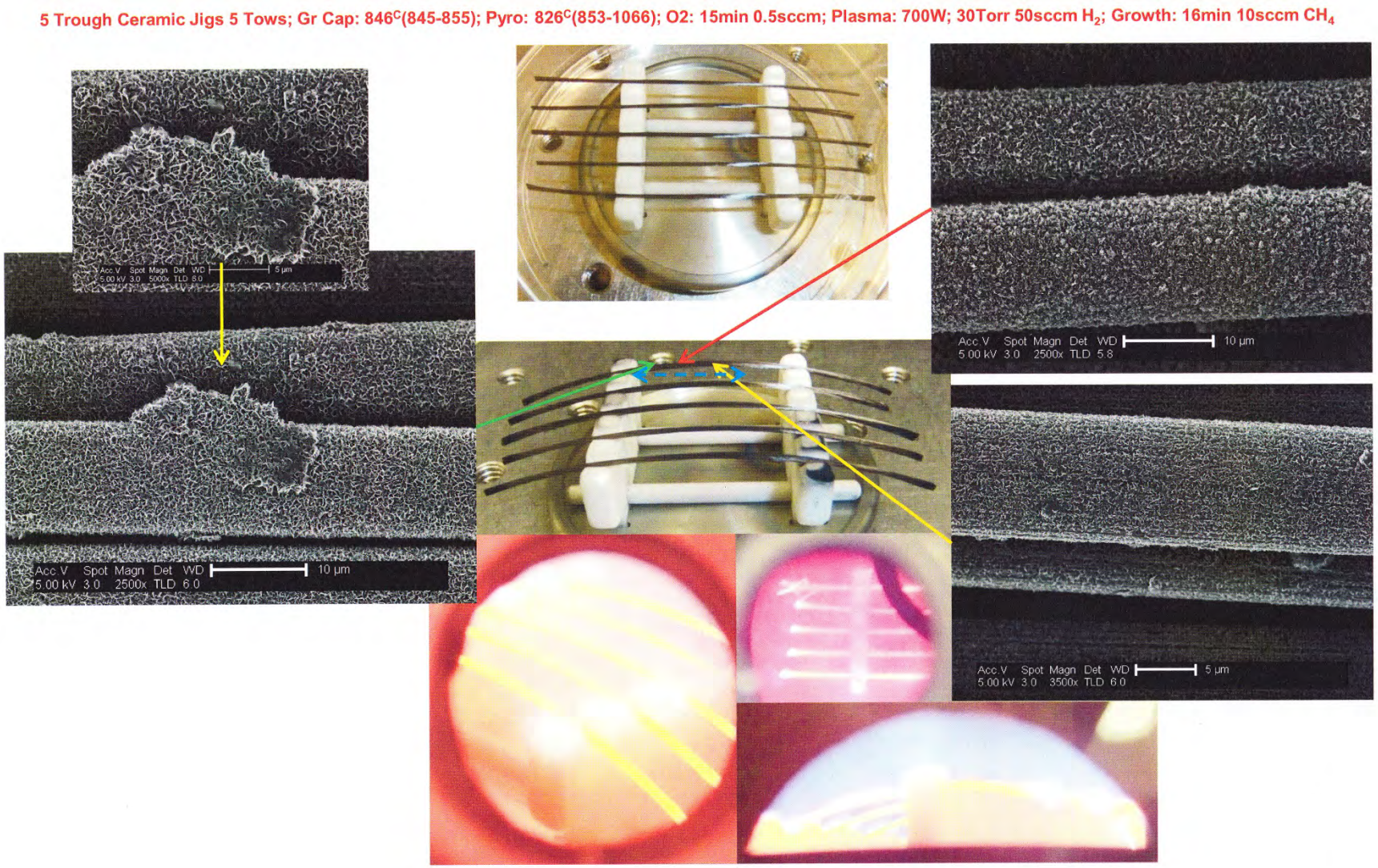


Figure FG82, P100S Fin Growth Un Capped Ceramic Jig O5a Position Side View

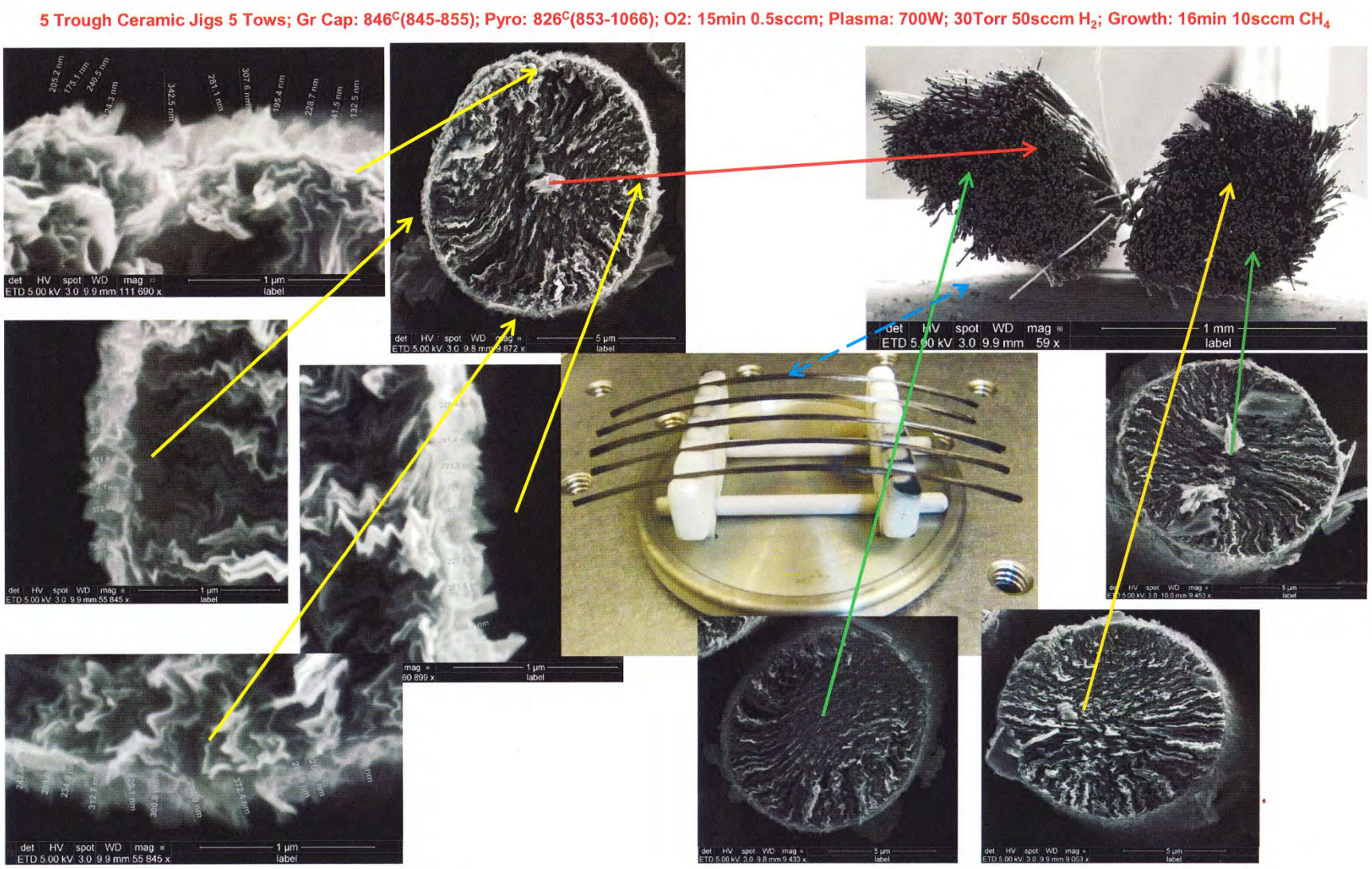


Figure FG83, P100S Fin Growth Un Capped Ceramic Jig O5a Position End View

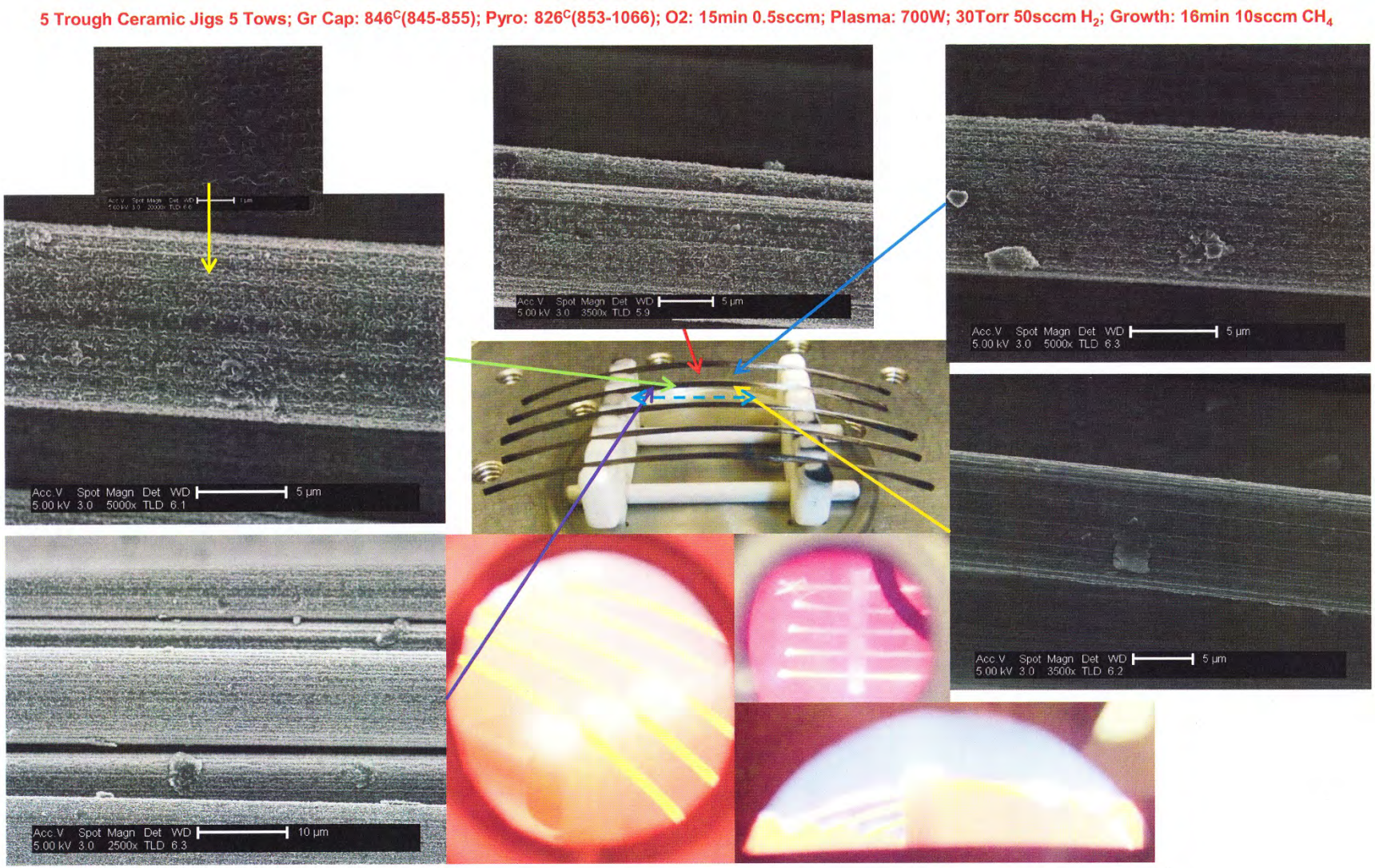


Figure FG84, P100S Fin Growth Un Capped Ceramic Jig M5a Position Side View

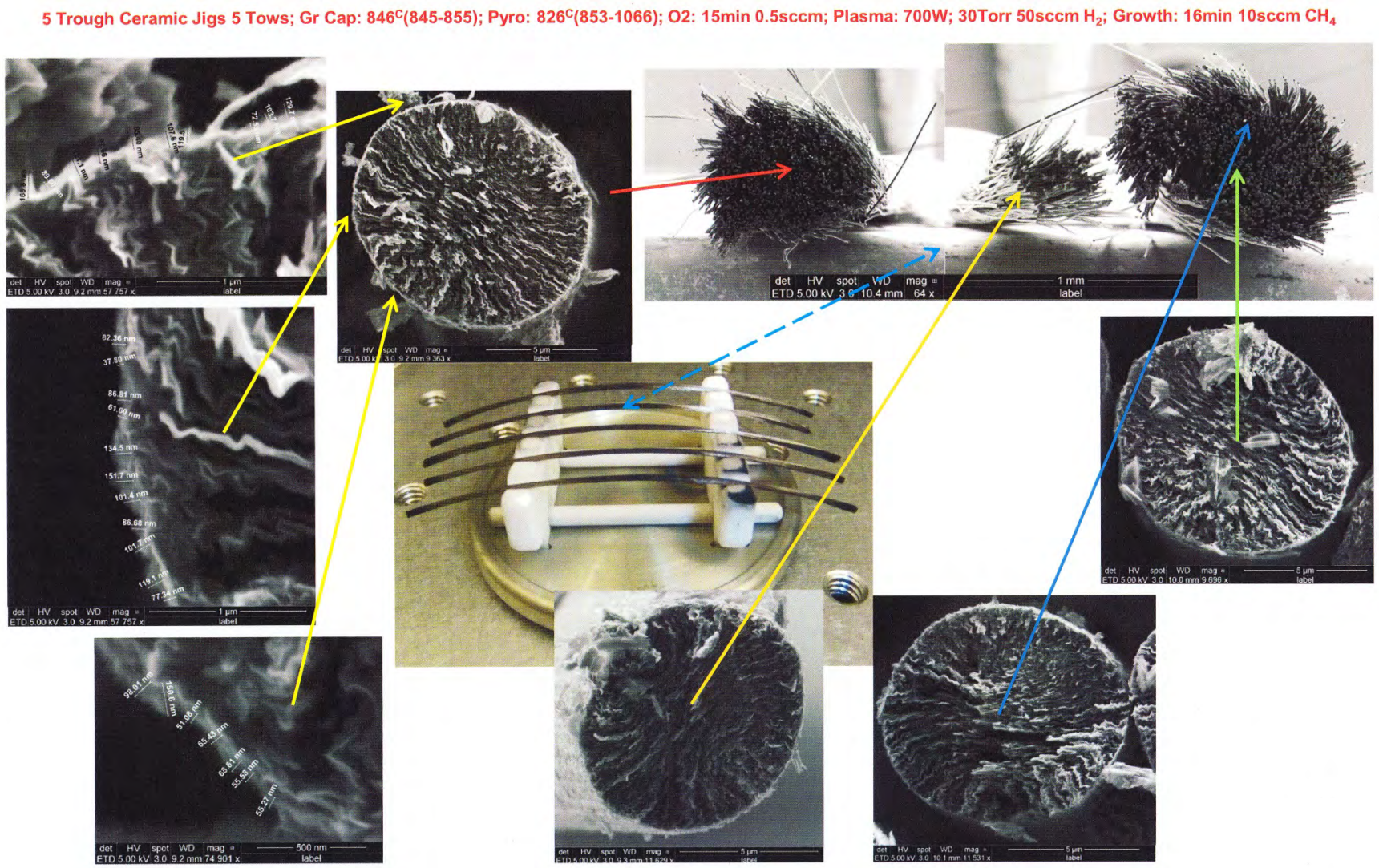


Figure FG85, P100S Fin Growth Un Capped Ceramic Jig M5a Position End View

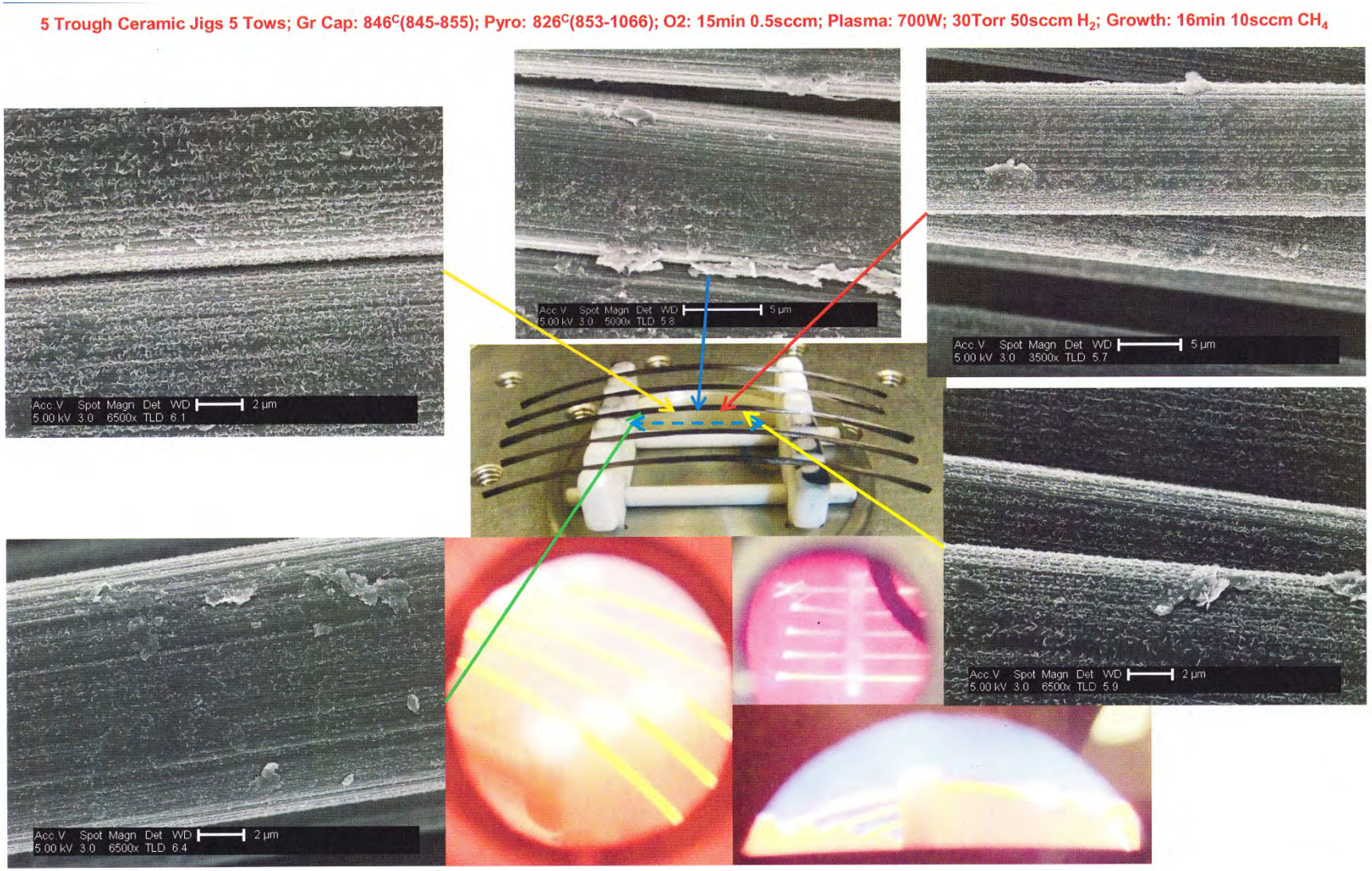


Figure FG86, P100S Fin Growth Un Capped Ceramic Jig C5 Position Side View

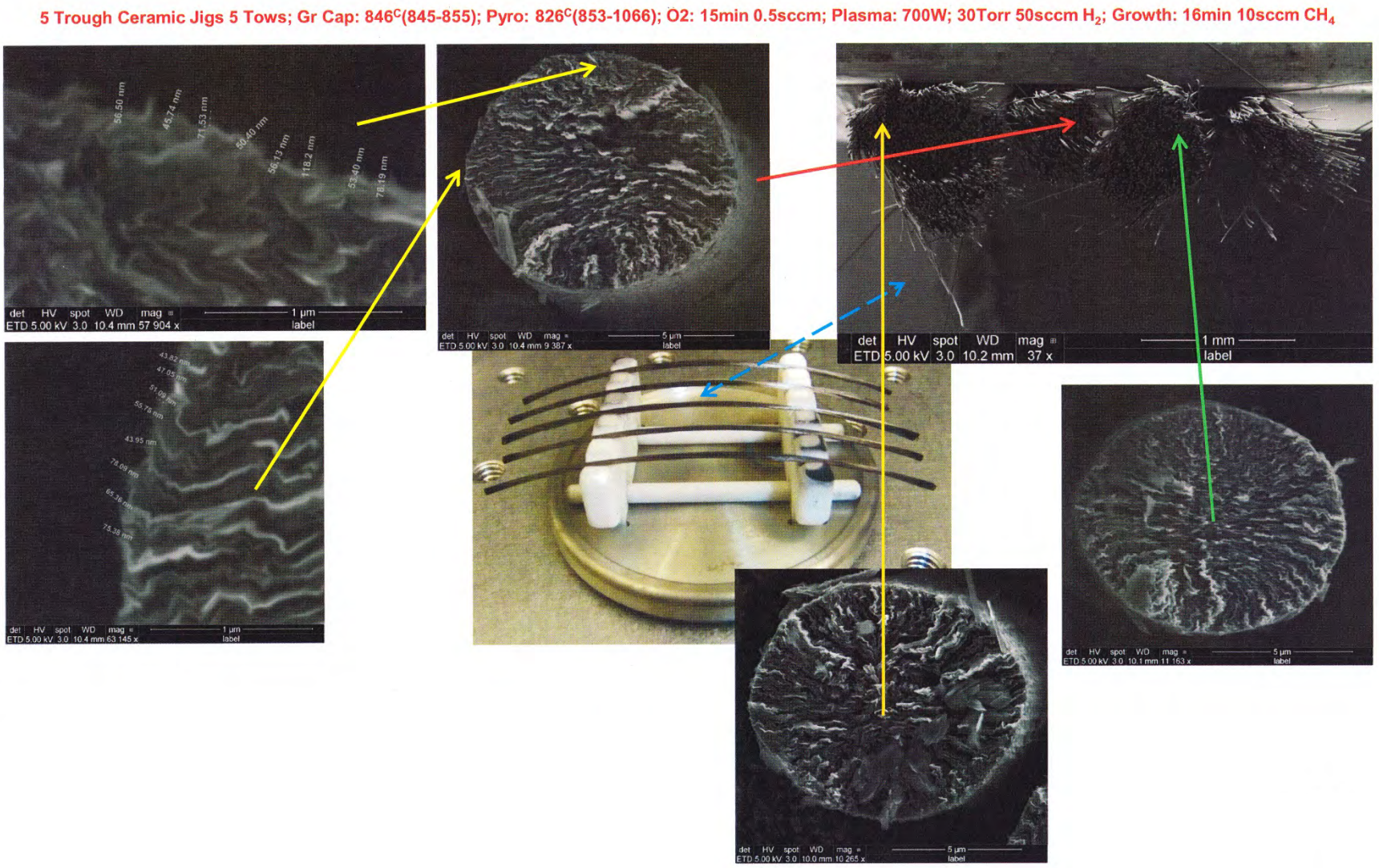


Figure FG87, P100S Fin Growth Un Capped Ceramic Jig C5 Position End View

5 Trough Ceramic Jigs 5 Tows; Gr Cap: 846^{C}(845-855); Pyro: 826^{C}(853-1066); O2: 15min 0.5sccm; Plasma: 700W; 30Torr 50sccm H_2; Growth: 16min 10sccm CH_4

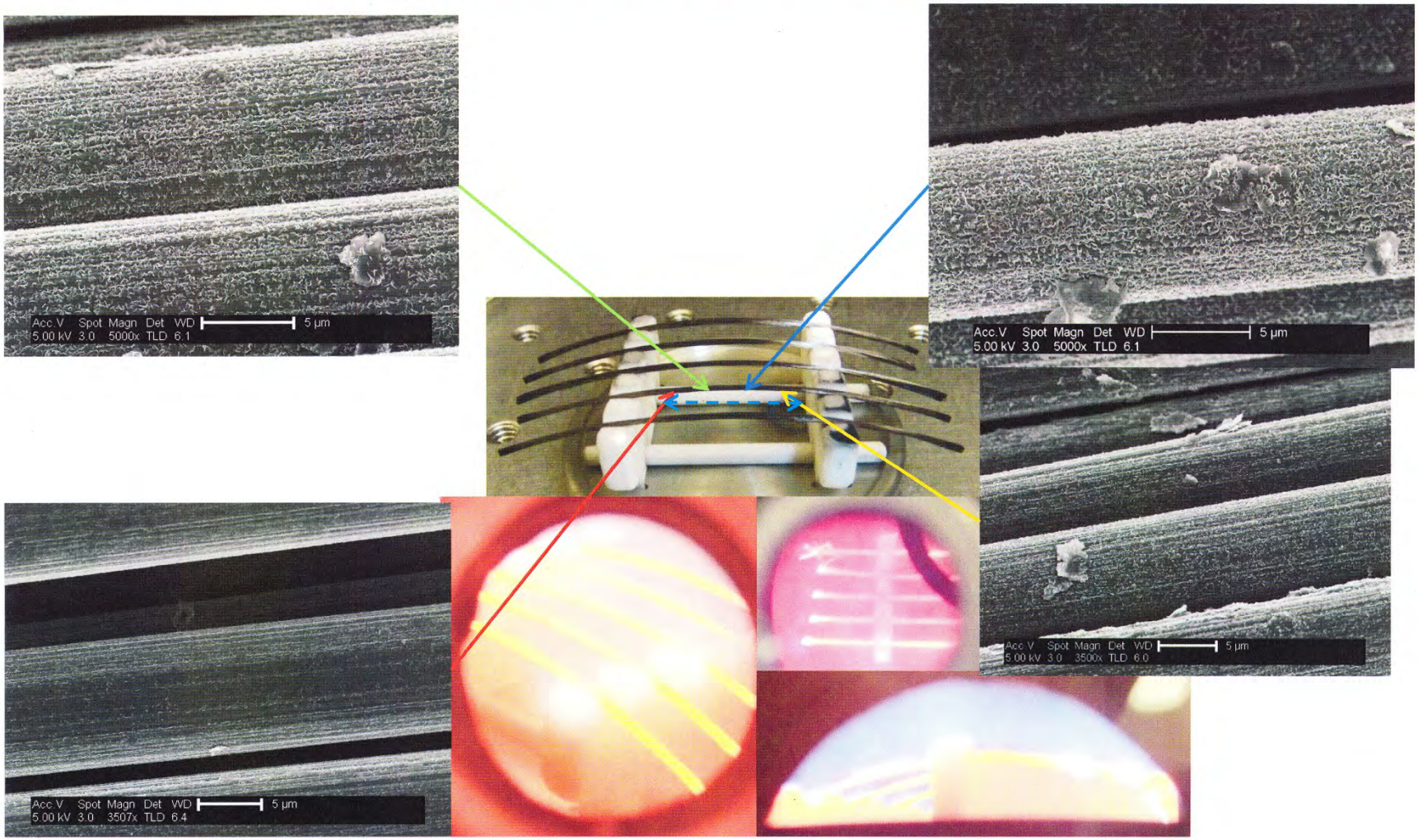


Figure FG88, P100S Fin Growth Un Capped Ceramic Jig M5b Position Side View

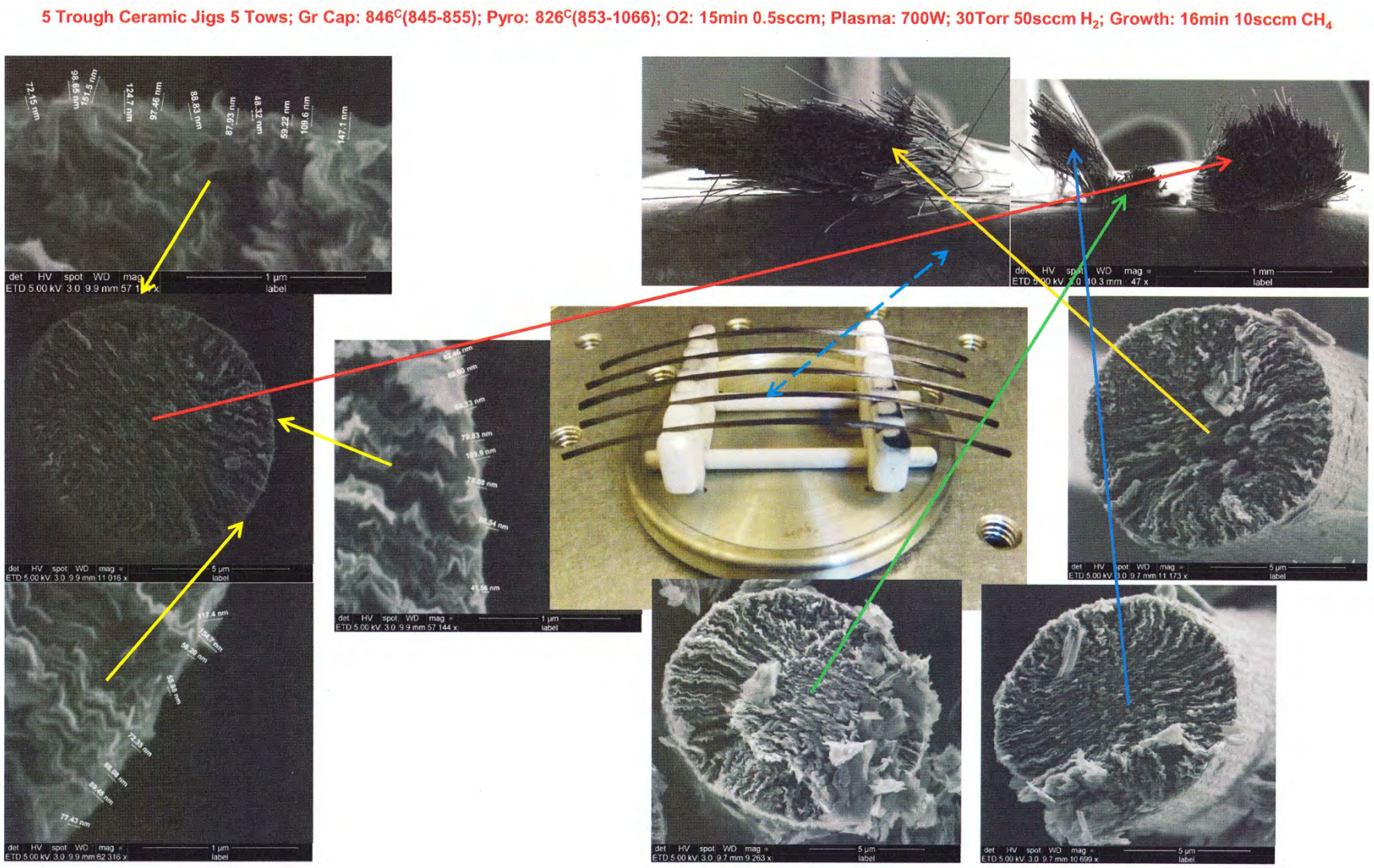


Figure FG89, P100S Fin Growth Un Capped Ceramic Jig M5b Position End View

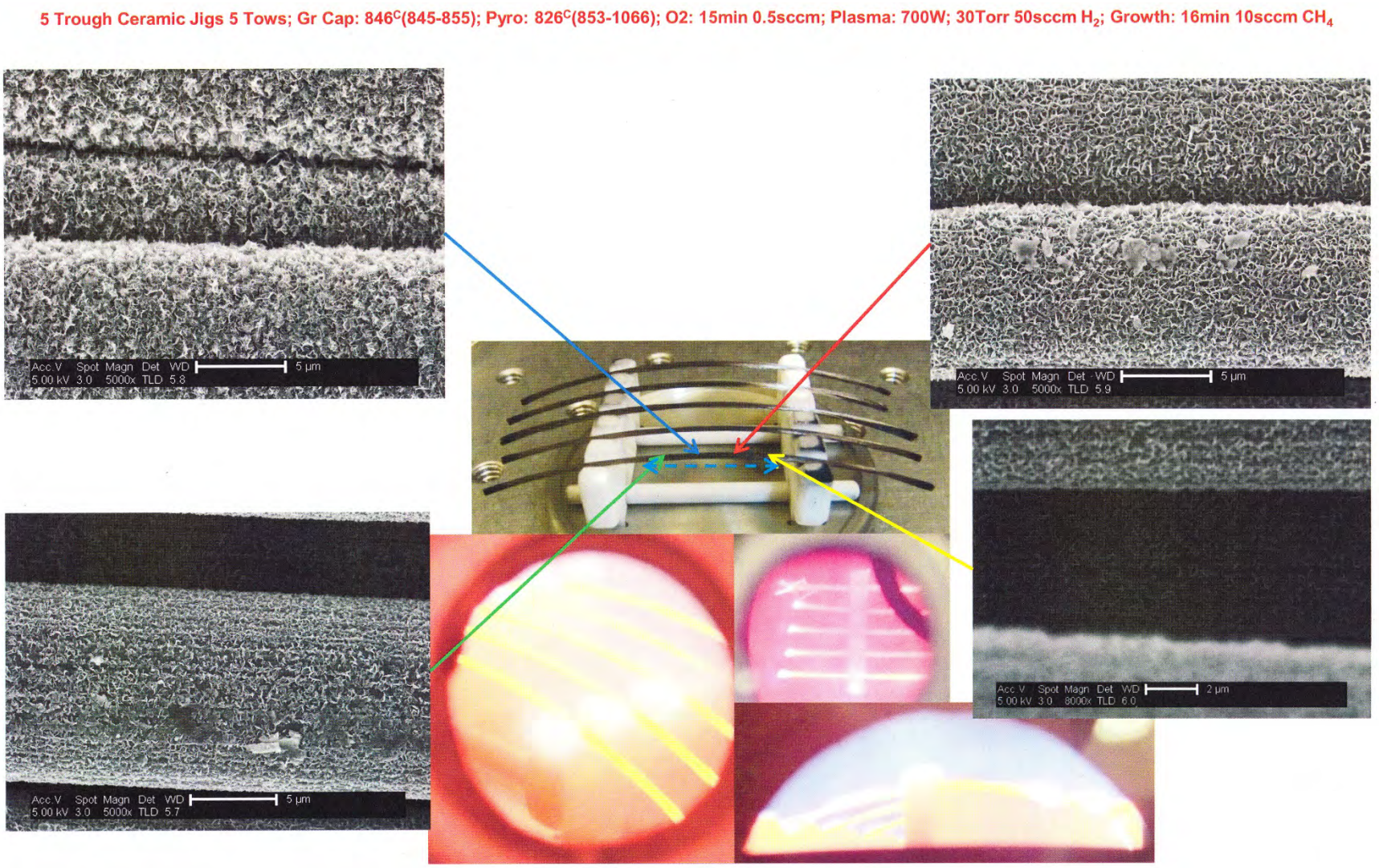


Figure FG90, P100S Fin Growth Un Capped Ceramic Jig O5b Position Side View

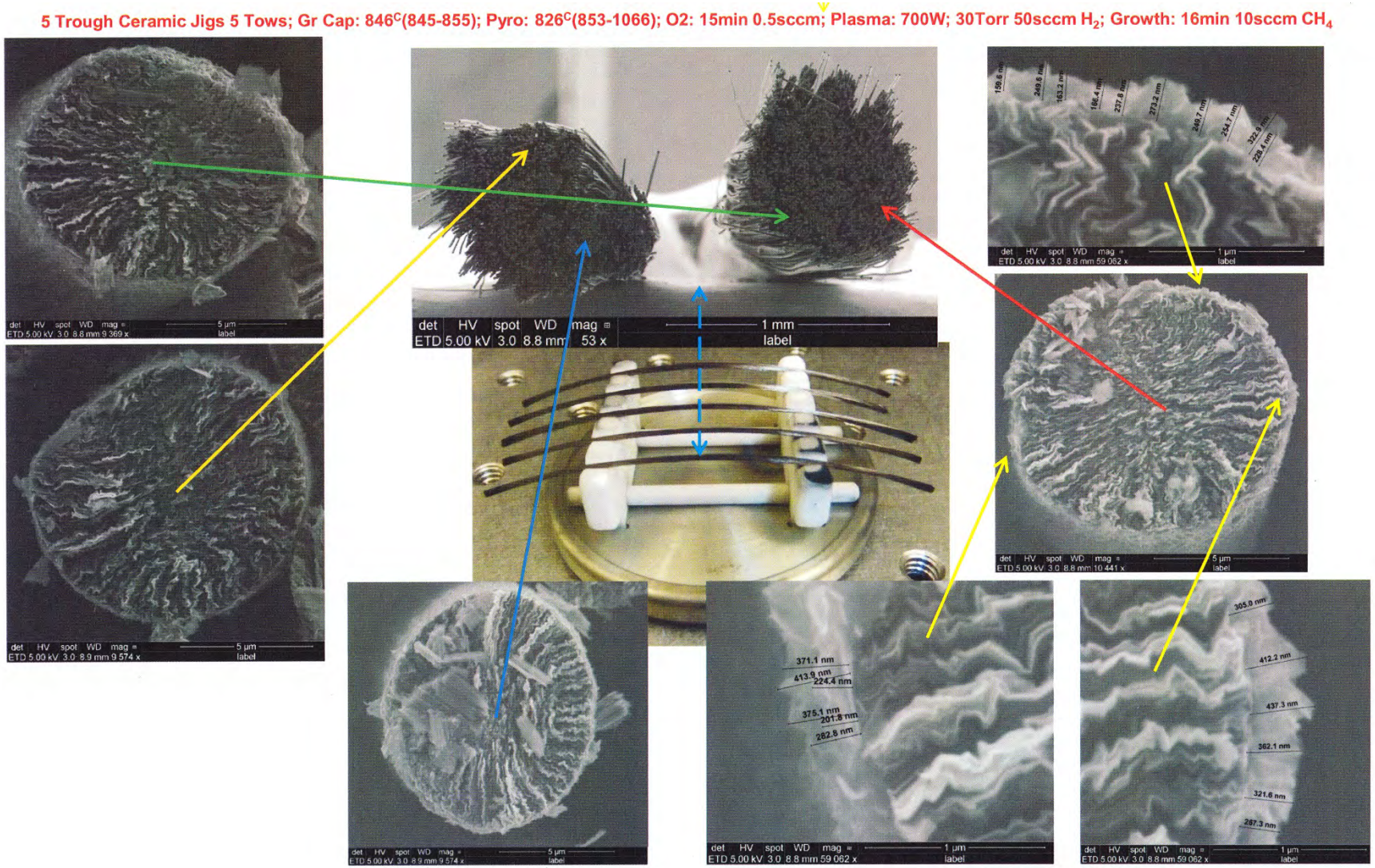


Figure FG91, P100S Fin Growth Un Capped Ceramic Jig O5b Position End View

3.12.3 Section 12-3: P100S 5 Capped Tow Fin Growth

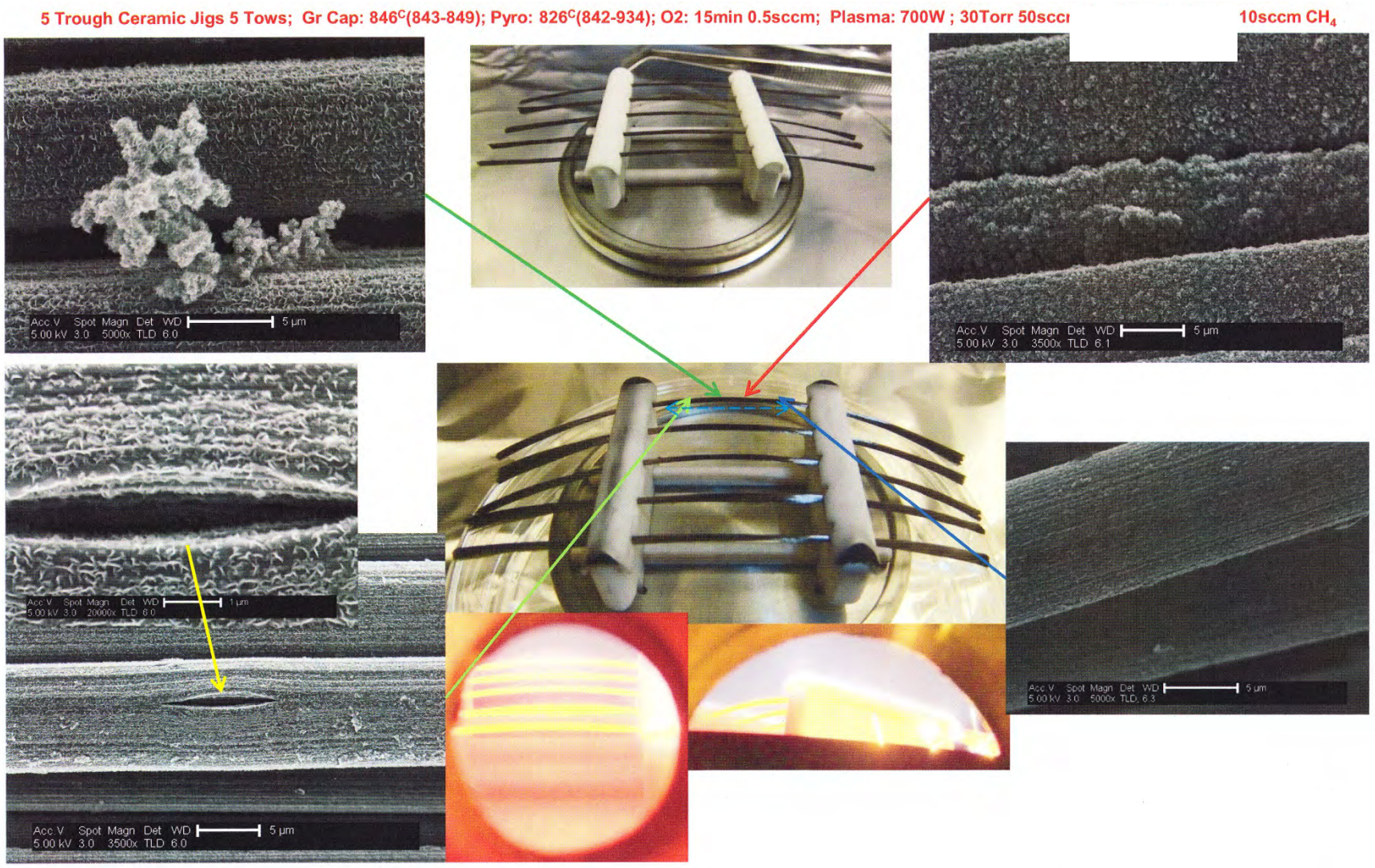


Figure FG92, P100S Fin Growth Capped Ceramic Jig O5a Position Side View

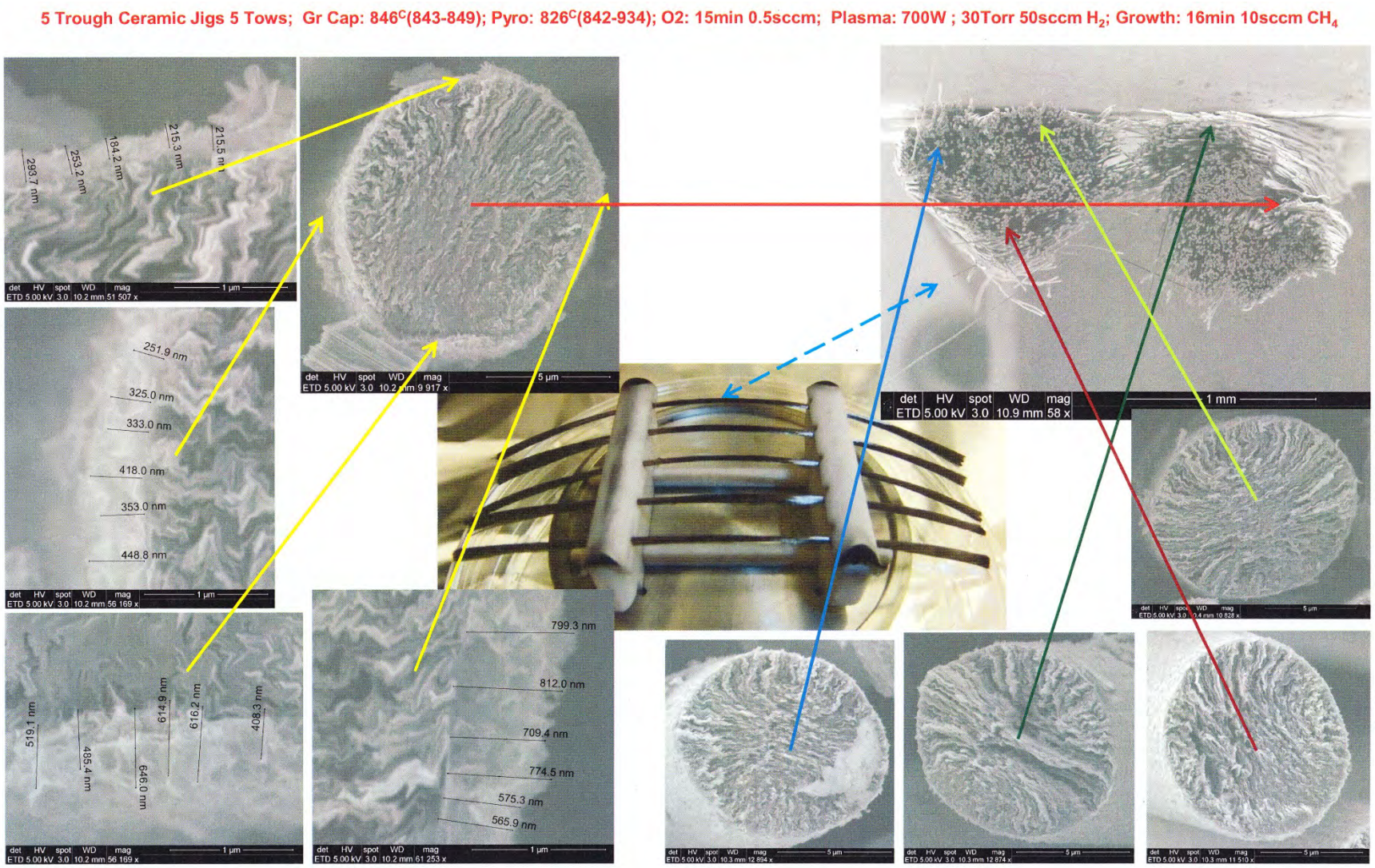


Figure FG93, P100S Fin Growth Capped Ceramic Jig O5a Position End View

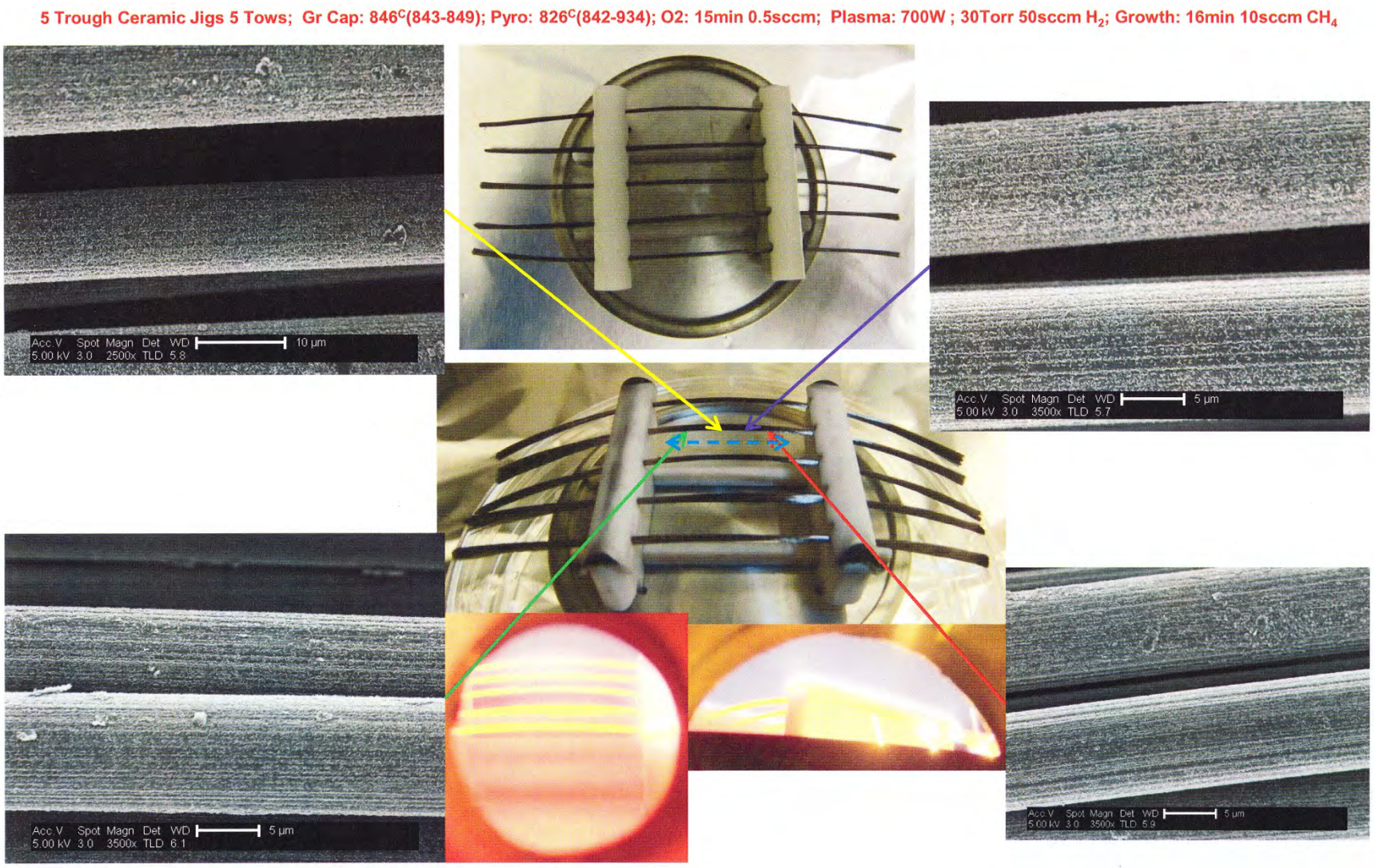


Figure FG94, P100S Fin Growth Capped Ceramic Jig M5a Position Side View

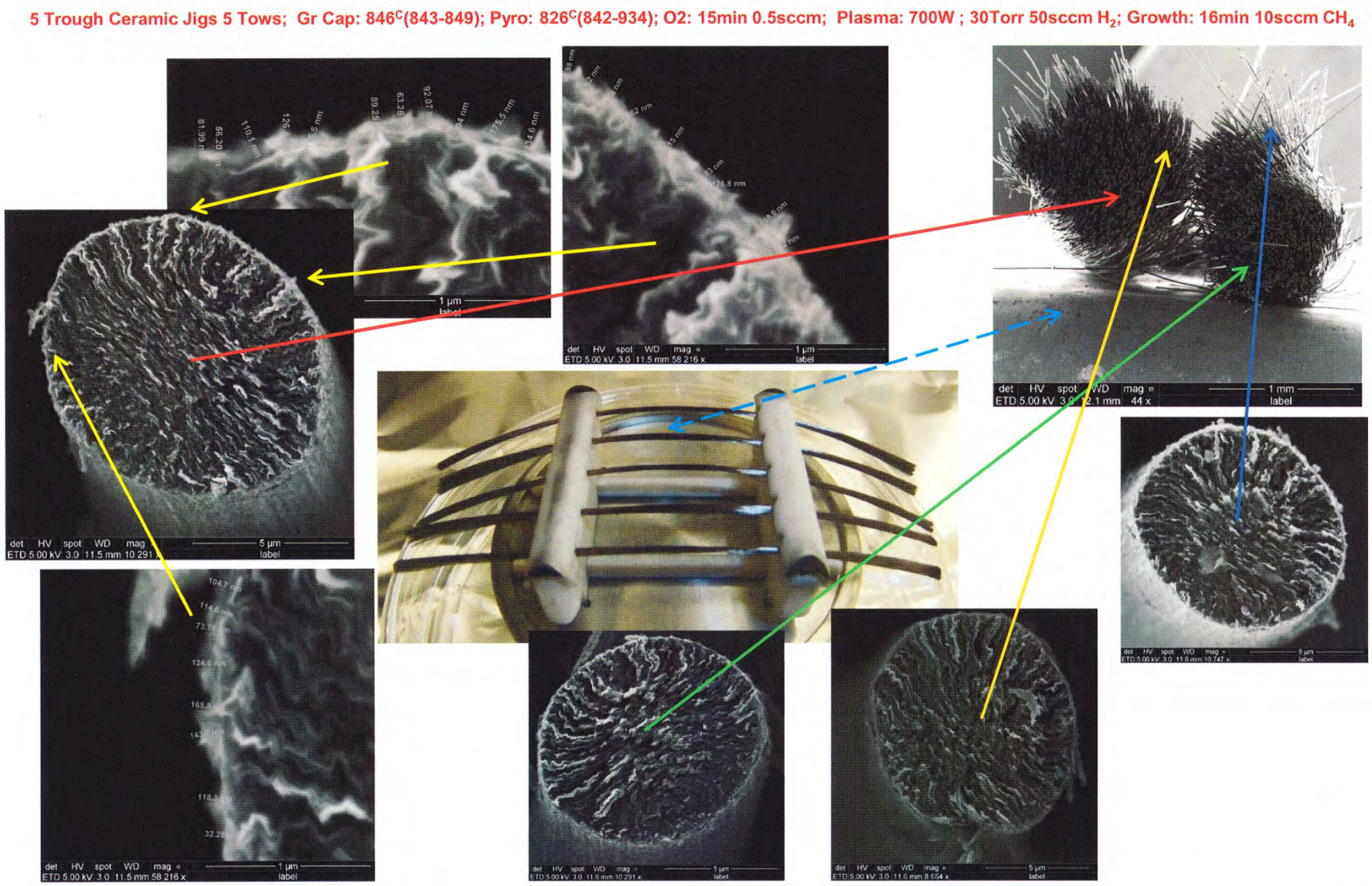


Figure FG95, P100S Fin Growth Capped Ceramic Jig M5a Position End View

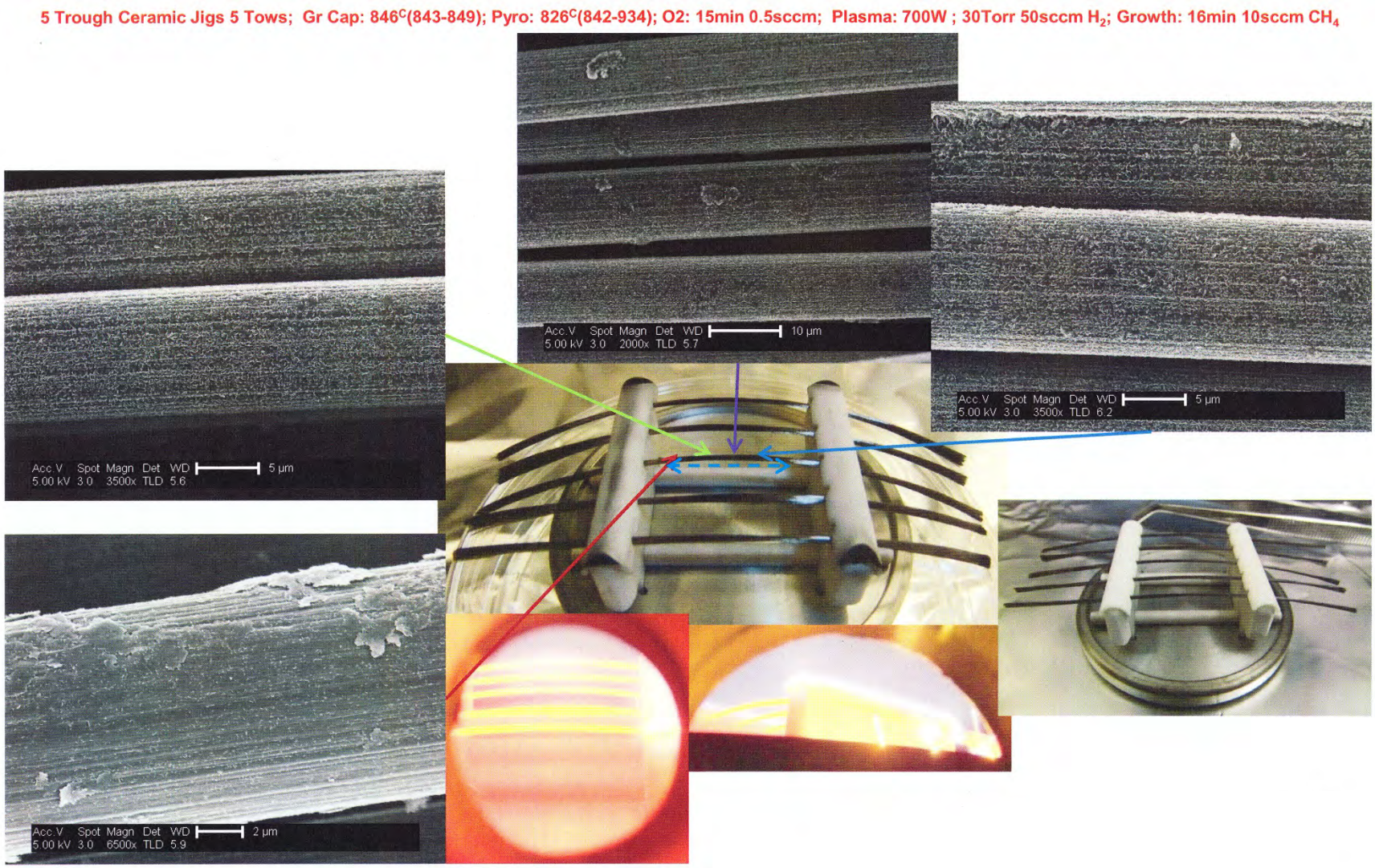


Figure FG96, P100S Fin Growth Capped Ceramic Jig C5 Position Side View

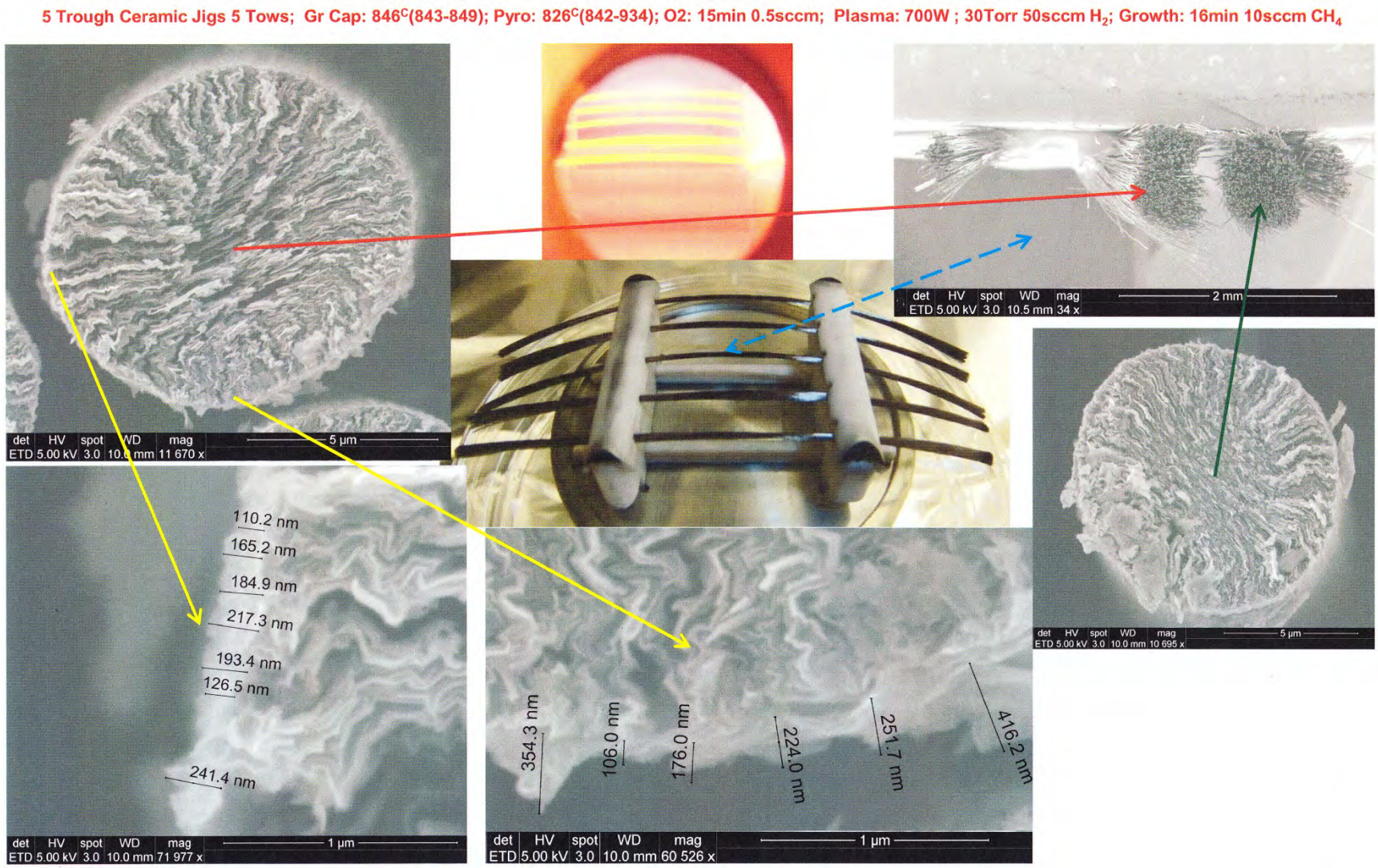


Figure FG97, P100S Fin Growth Capped Ceramic Jig C5 Position End View

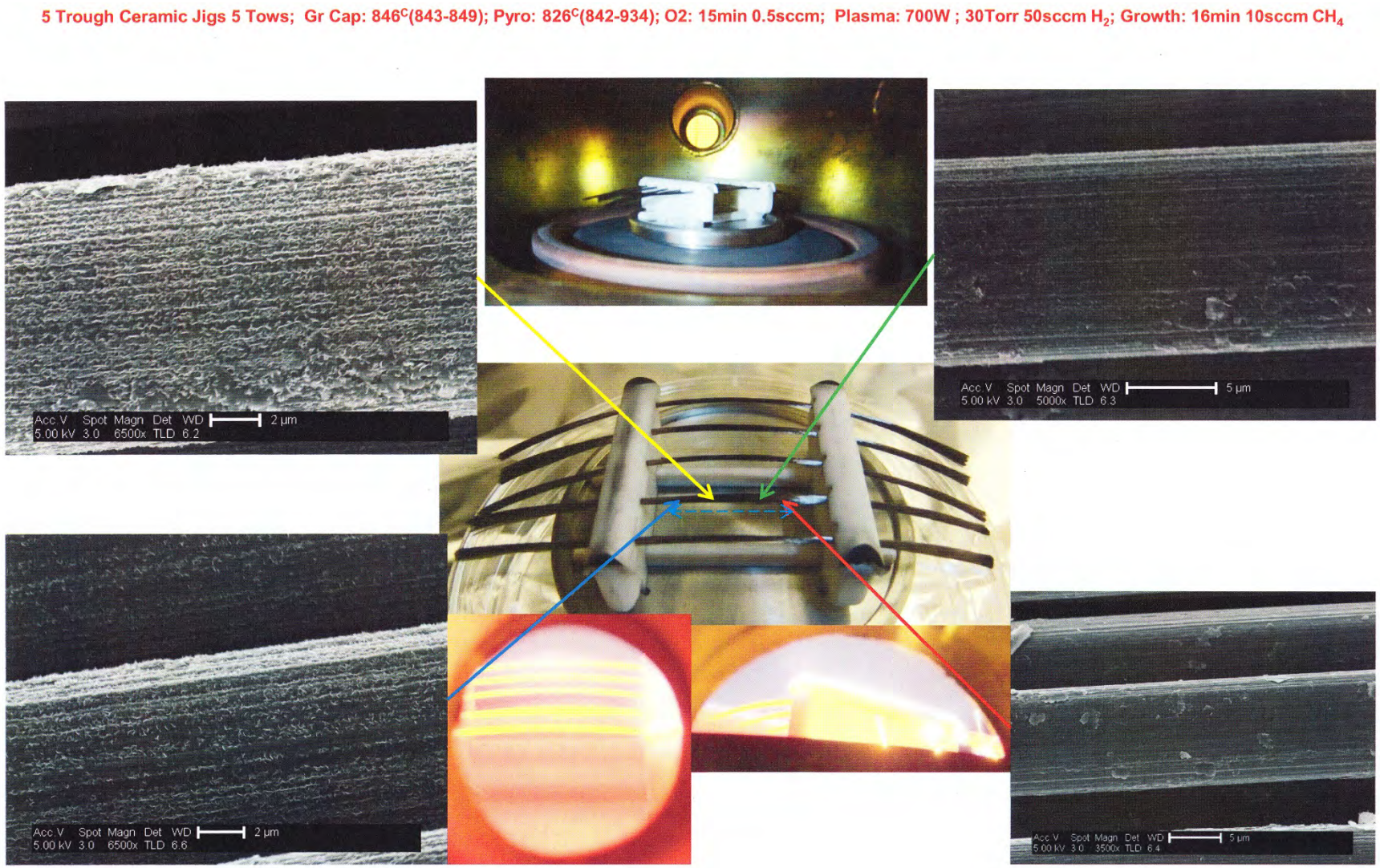


Figure FG98, P100S Fin Growth Capped Ceramic Jig M5b Position Side View

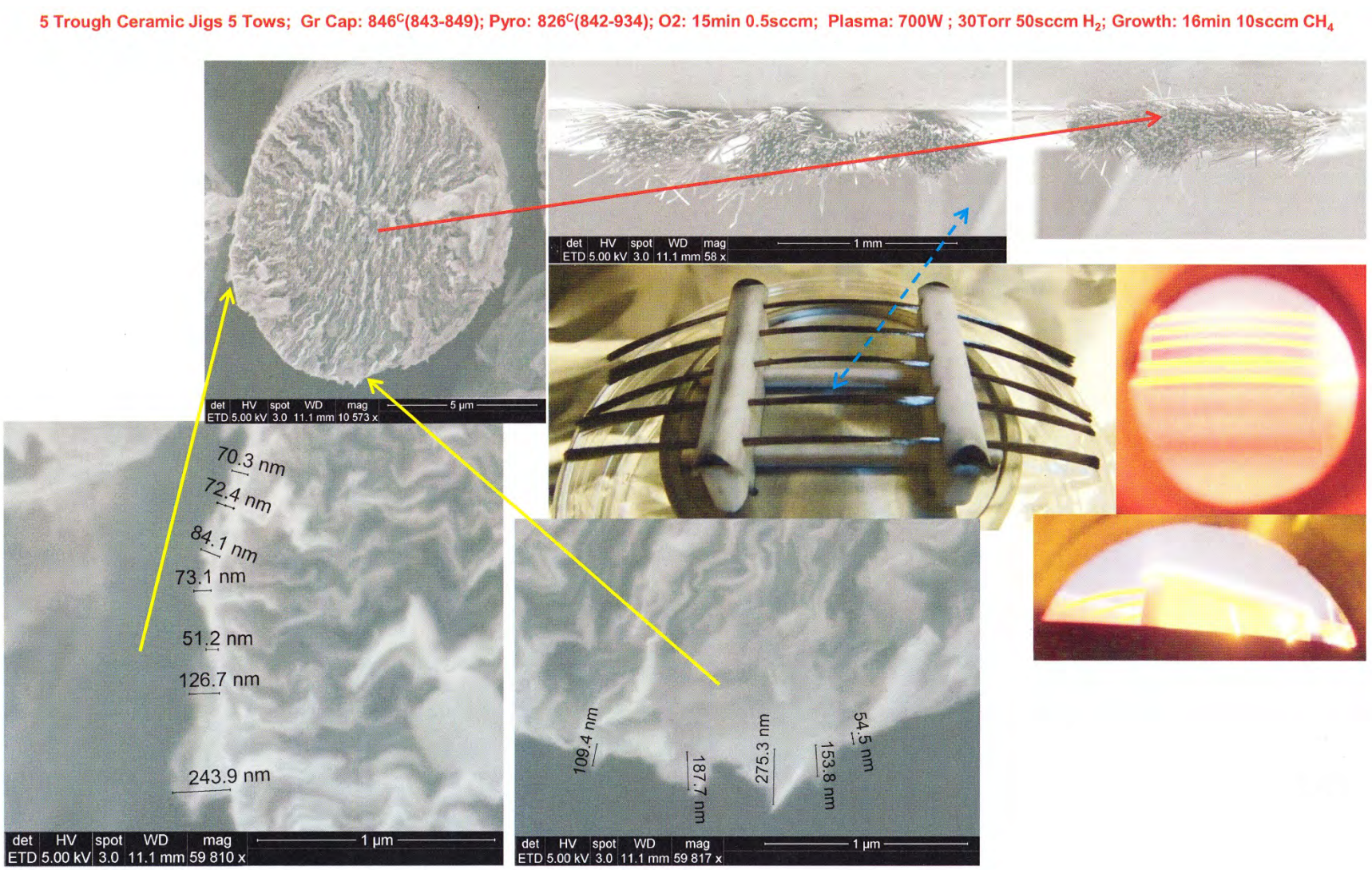


Figure FG99, P100S Fin Growth Capped Ceramic Jig M5b Position End View

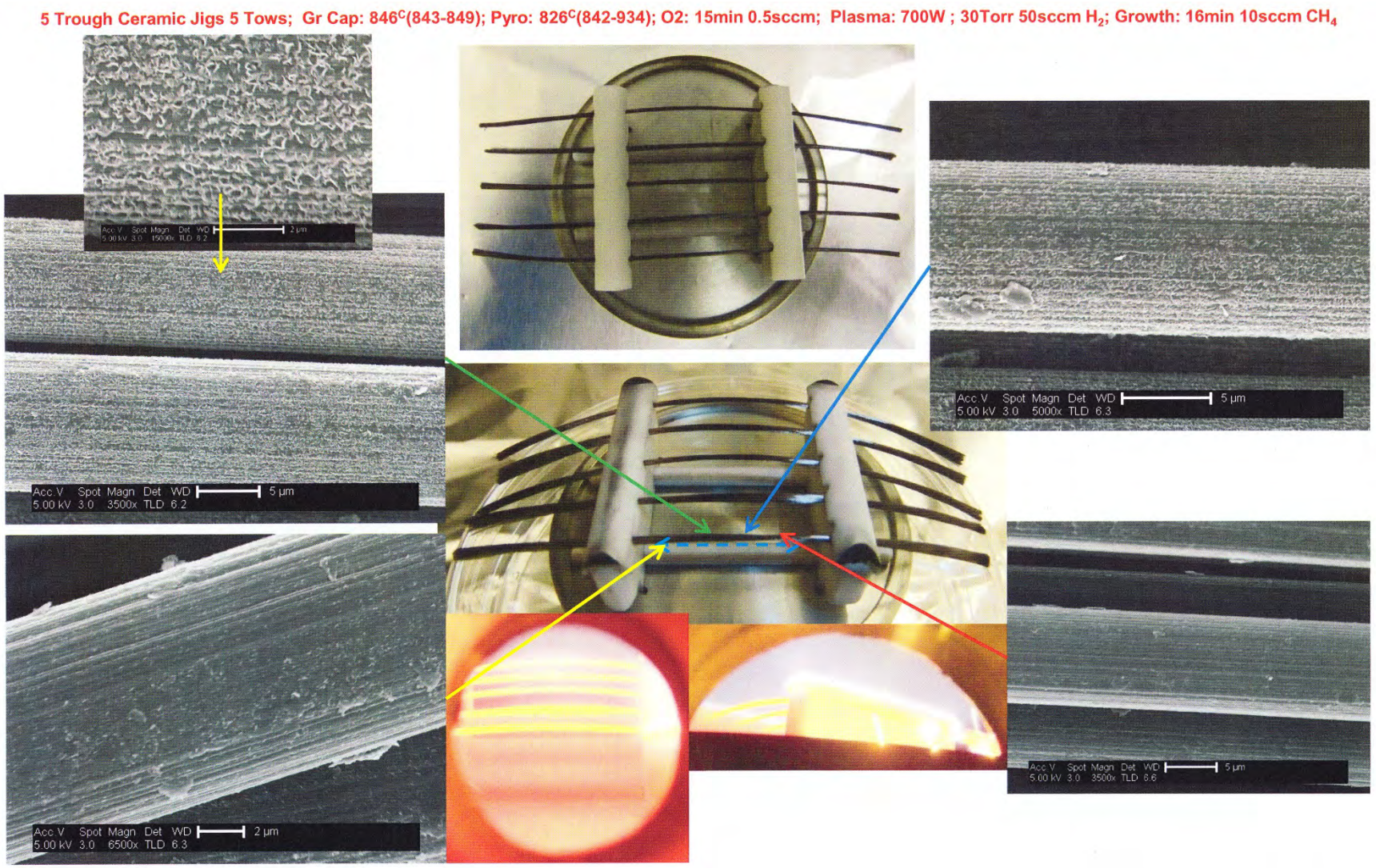


Figure FG100, P100S Fin Growth Capped Ceramic Jig O5b Position Side View

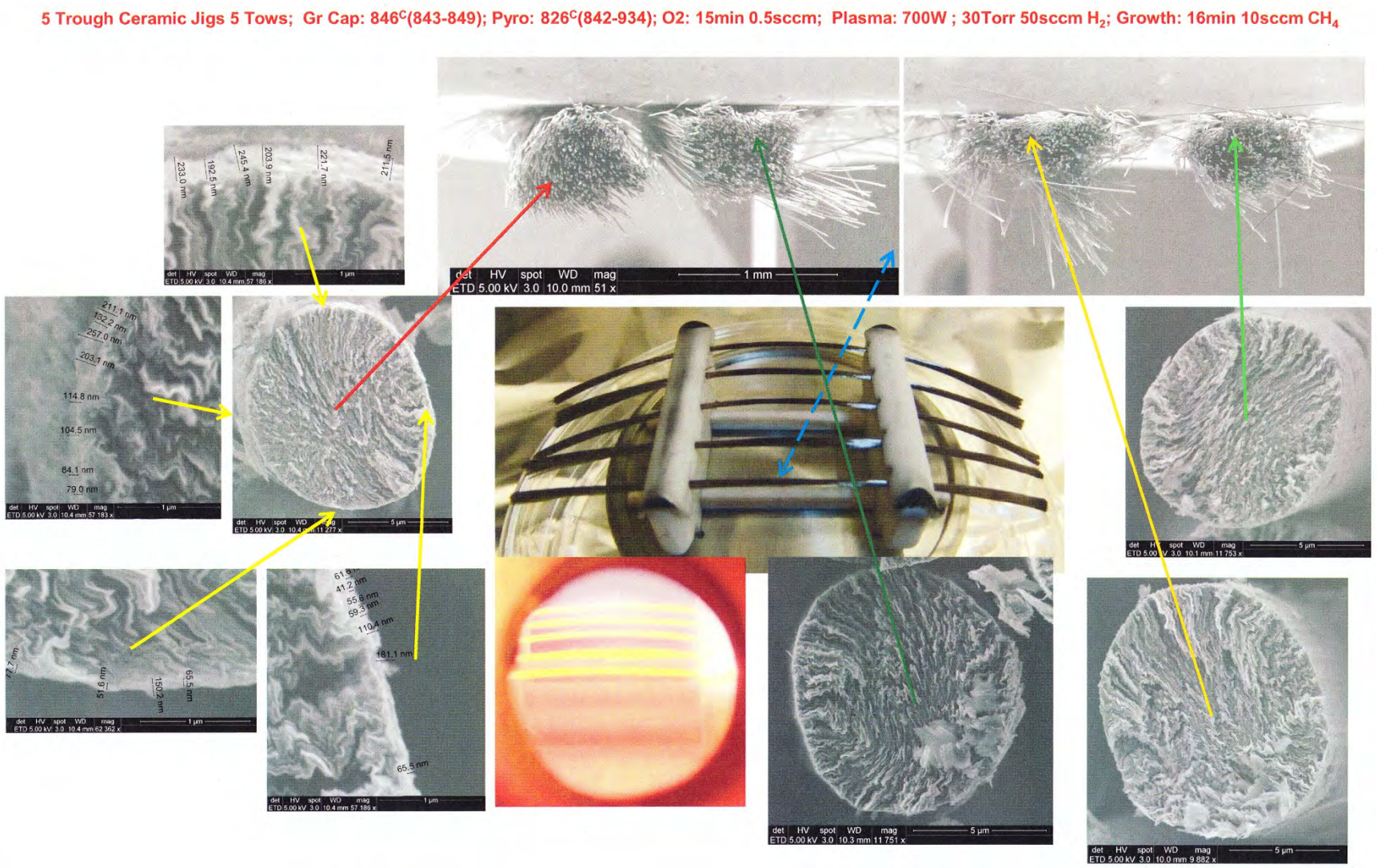
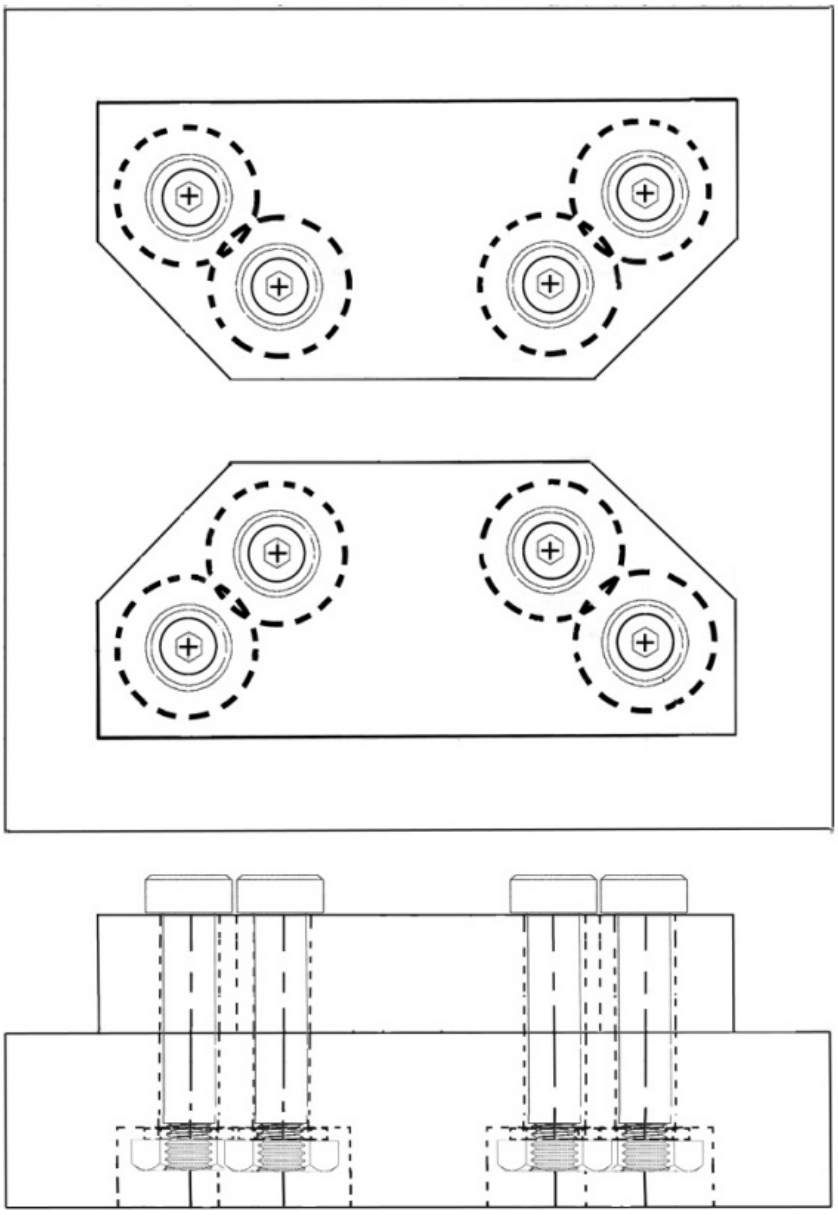


Figure FG101, P100S Fin Growth Capped Ceramic Jig O5b Position End View

4.0 APPENDIX B: BULK COMPOSITE FABRICATION

4.1 Section 1: Composite Lay Up Jig Design



Parts List:

1. One Base Plate
2. Two Fence Plates
3. Eight 8-32 1″ 4140 Alloy Steel Socket Head Shoulder Screws
4. Eight 8-32 Stainless Steel Hex Nuts
5. Eight 11/64″ ID 3/8″ OD Stainless Steel Washers

SBS Composite Lay Up and Bonded Laser Flash Specimens Assembly Jig
Engineer: Roger Gerzeski Date: Rev A 14 Jul 2010, Org 1 Dec2009

Figure BCF1, Bulk Composite Lay Up Jig Assembly Design

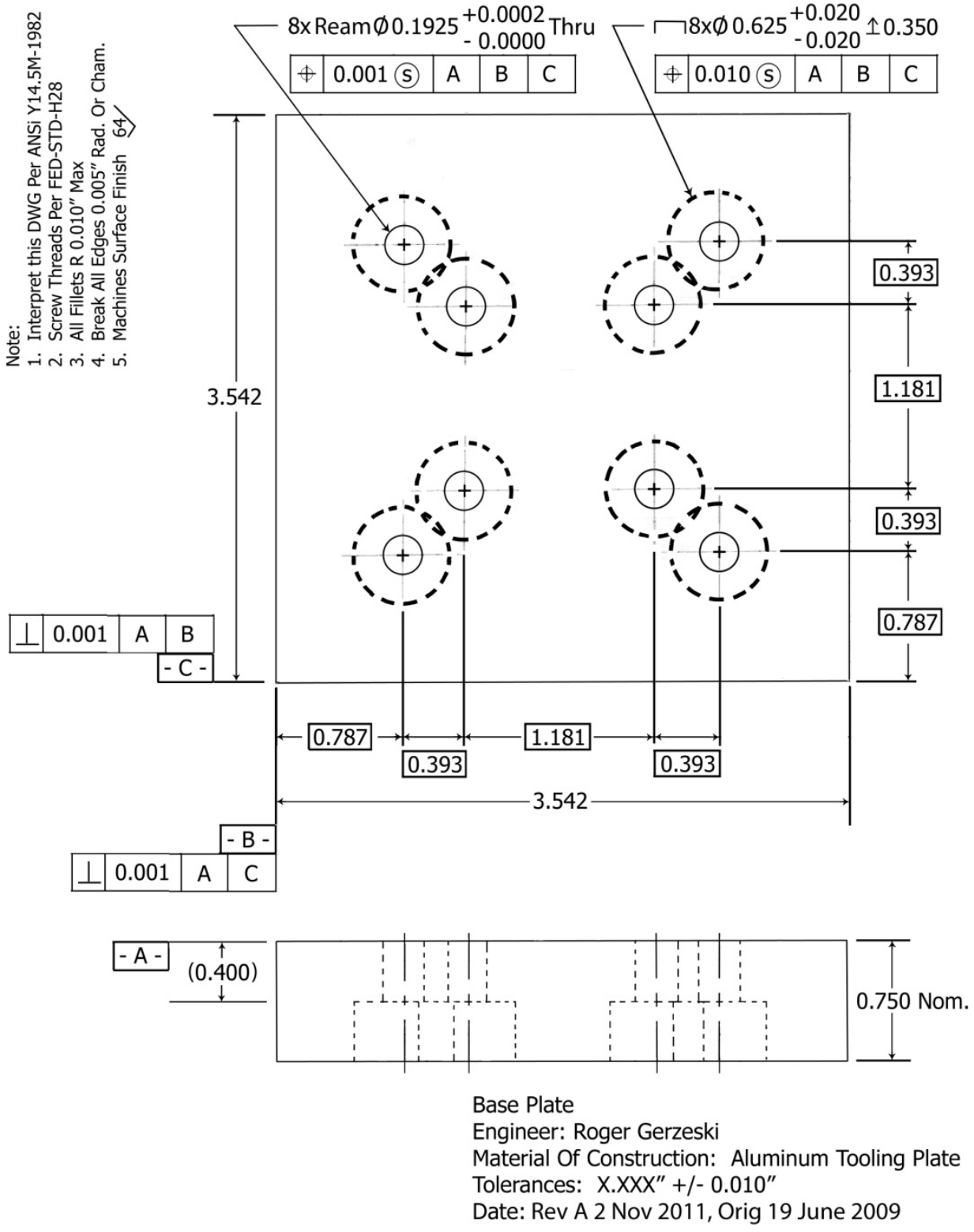
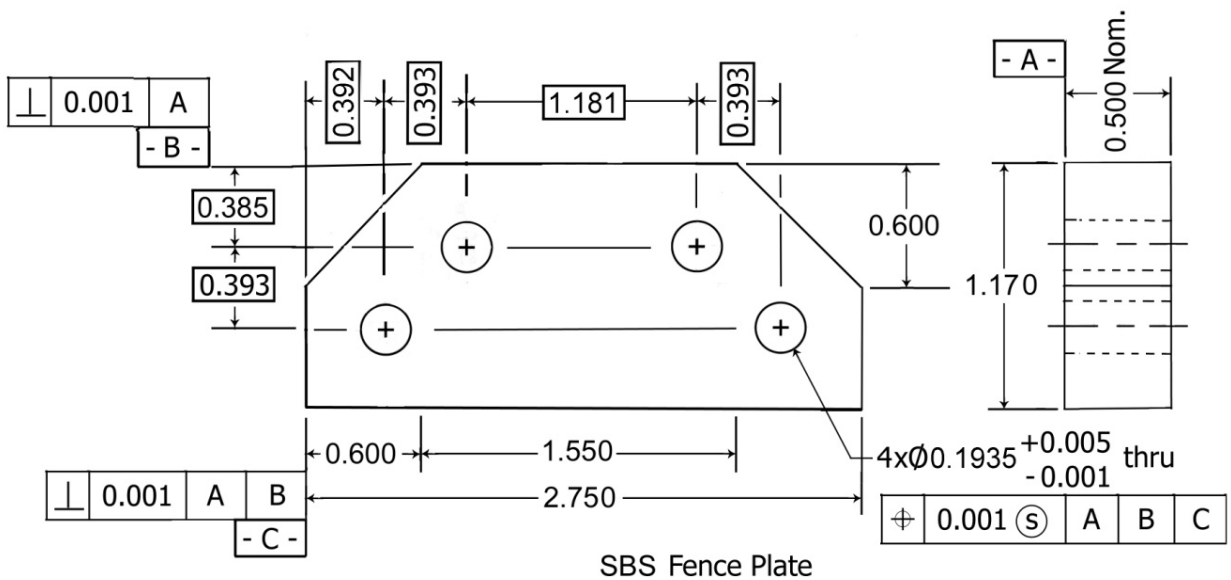


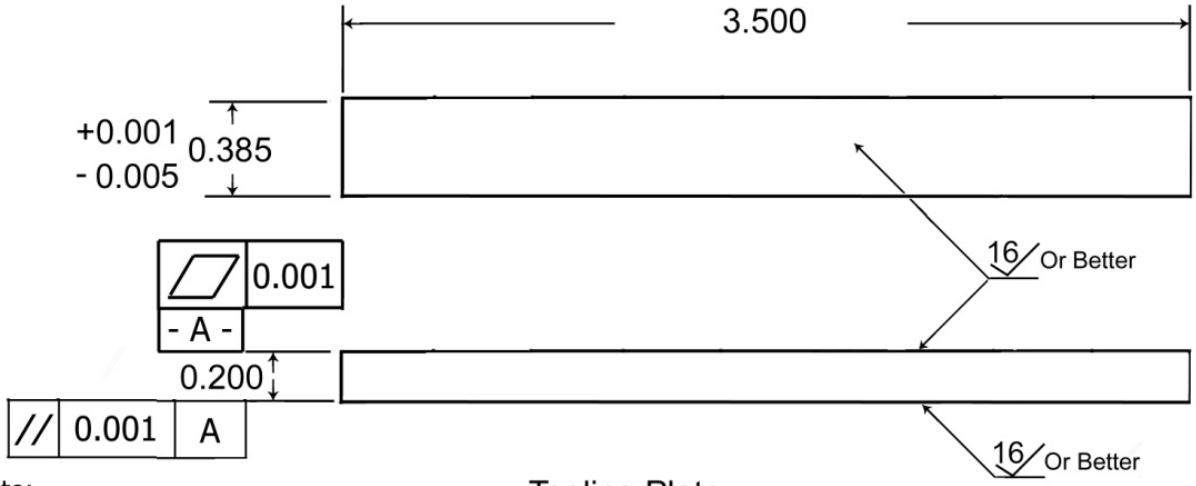
Figure BCF2, Jig Base Plate Design



SBS Fence Plate
Engineer: Roger Gerzeski
Material Of Construction: Aluminum Tooling Plate
Tolerances: X.XXX" +/- 0.005"
Date: Rev B 24 Sep 2011,
Rev A 14 Jul 2010,
Org 1 Dec 2009

Note:
1. Interpret this DWG Per ANSi Y14.5M-1982
2. Screw Threads Per FED-STD-H28
3. All Fillets R 0.010" Max
4. Break All Edges 0.005" Rad. Or Cham.
5. Machines Surface Finish 64

Figure BCF3, Fence Plate Design



Tooling Plate
Engineer: Roger Gerzeski
Material Of Construction: Pyrolytic Graphite
Tolerances: X.XXX +/- 0.010"
Date: Rev A 4 Nov 2011, Orig 1 Dec 2009

Note:
1. Interpret this DWG Per ANSi Y14.5M-1982
2. Screw Threads Per FED-STD-H28
3. All Fillets R 0.010" Max
4. Break All Edges 0.005" Rad. Or Cham.
5. Machines Surface Finish 64

Figure BCF4, Graphite Tooling Plate Design

4.2 Section 2: Exploded Composite Lay Up Jig

Figure BCF5, Exploded Composite Lay Up Jig Side View

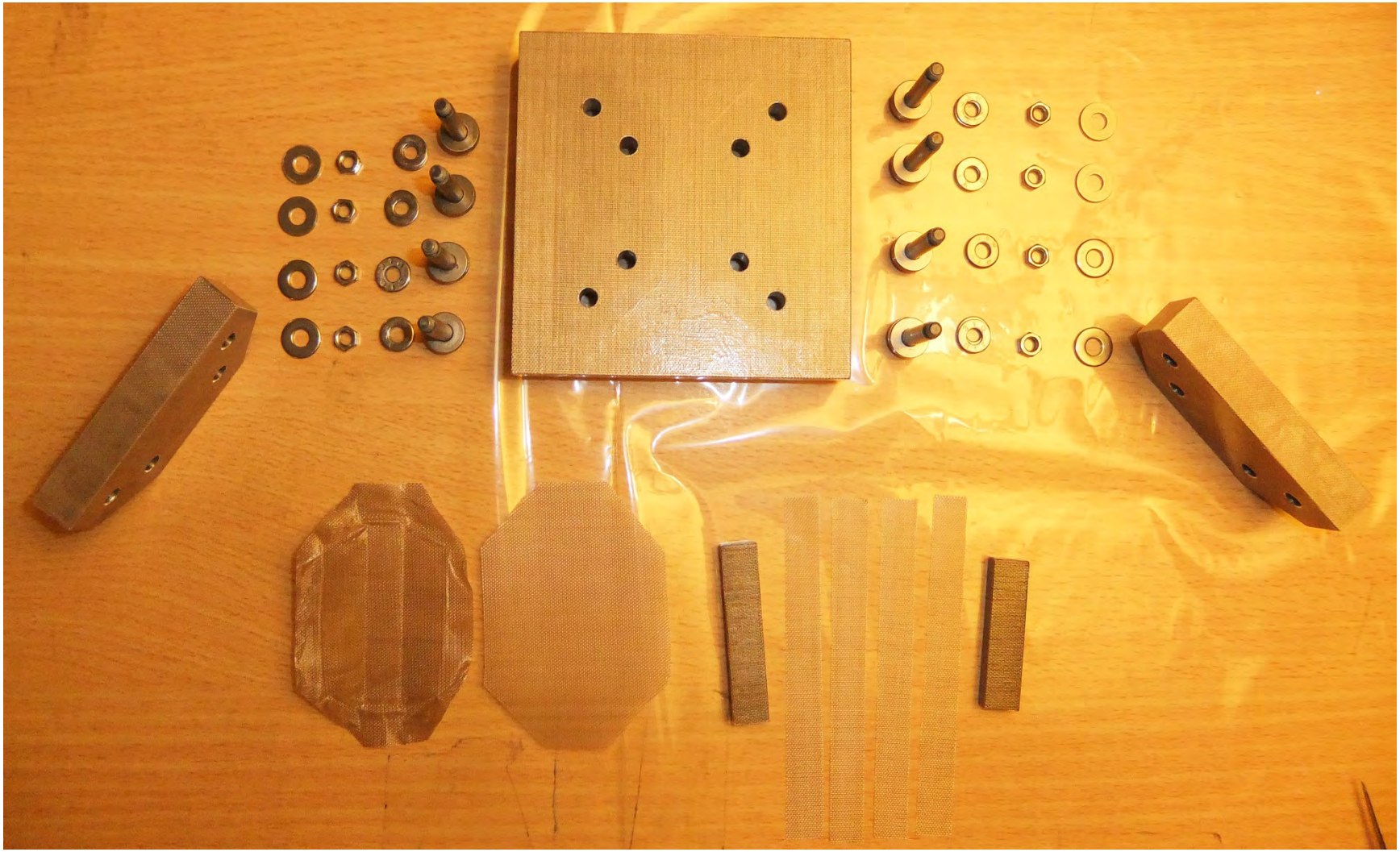


Figure BCF6, Exploded Composite Lay Up Jig Top View

4.3 Section 3: Assembled Composite Lay Up Jig

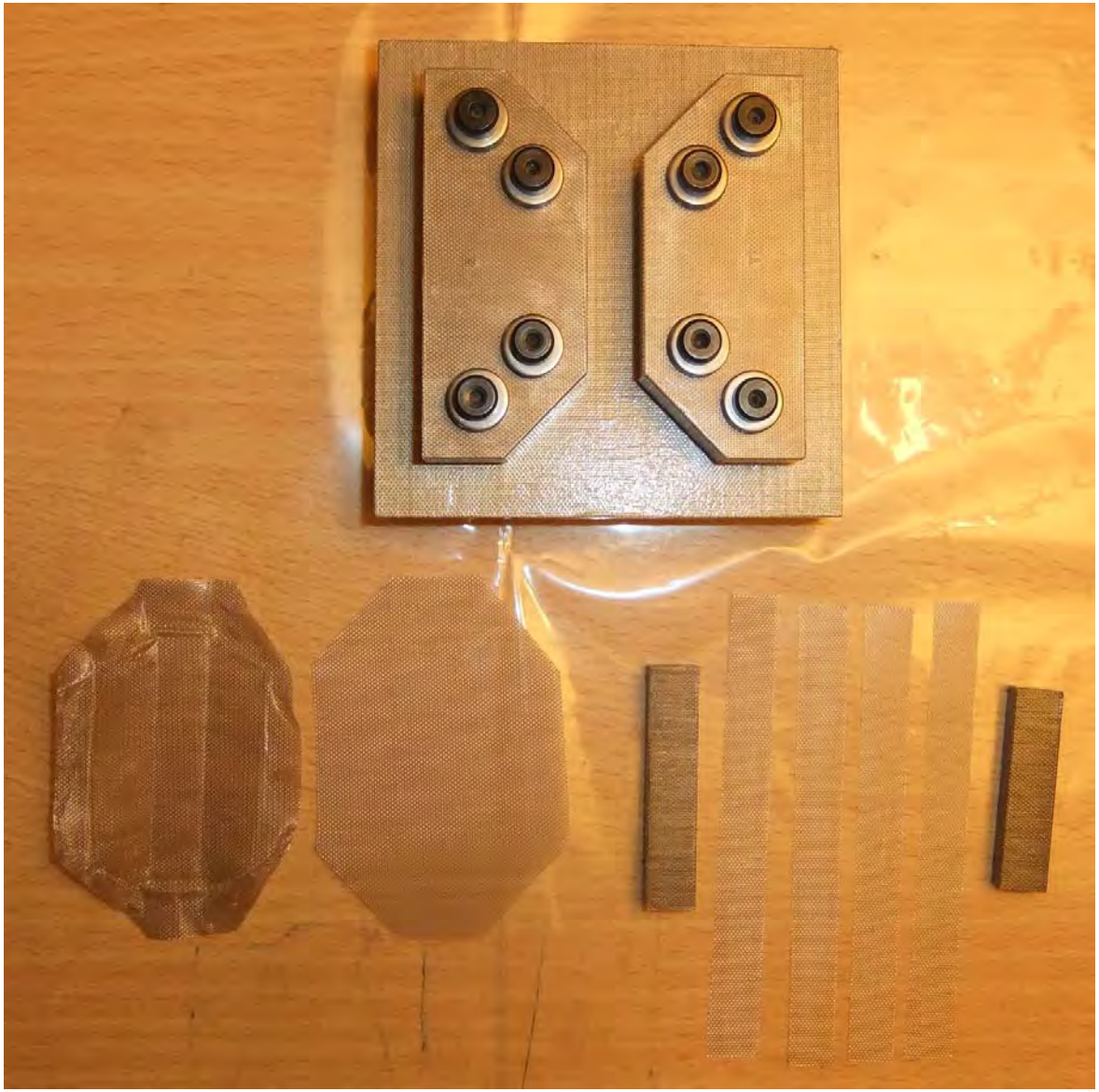


Figure BCF7, Assembled Composite Lay Up Jig Top Down View

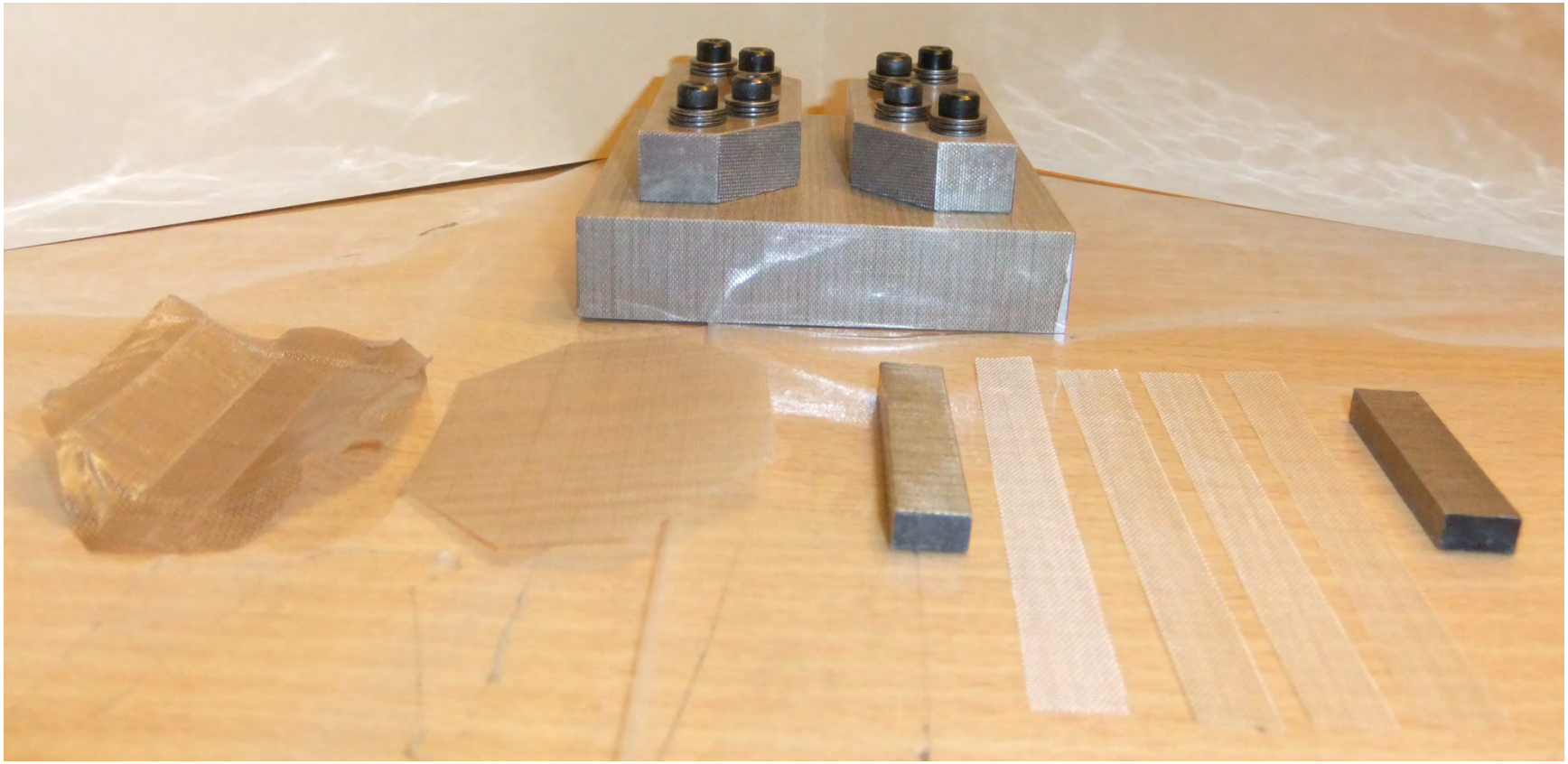


Figure BCF8, Assembled Composite Lay Up Jig Side View

4.4 Section 4: Release Ply Insertion

Figure BCF9, Release Ply Top Side View

4.5 Section 5: Bleed Ply Insertion

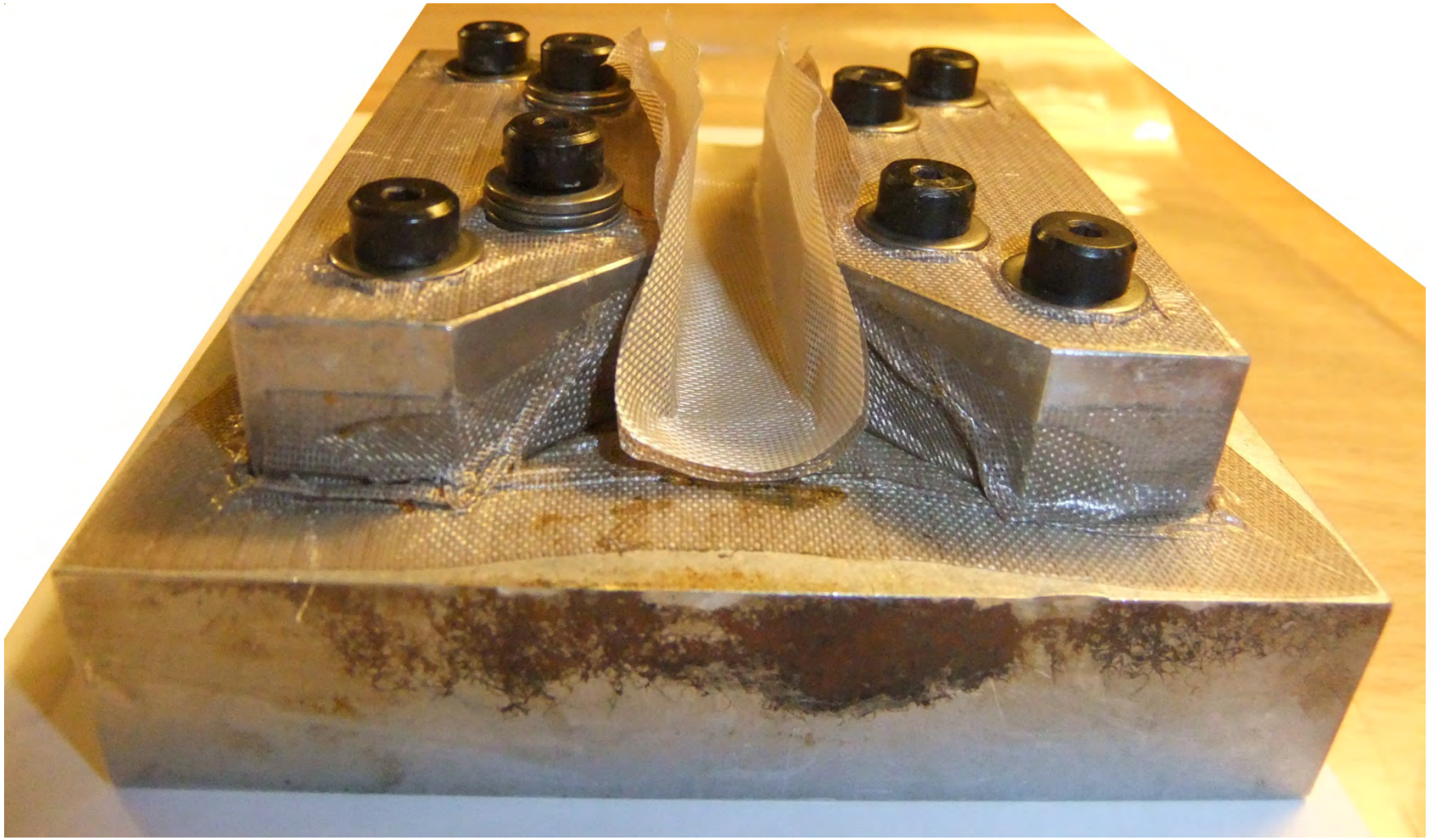


Figure BCF10, Bleed Ply Insertion Top Side View

4.6 Section 6: Bottom Graphite Tooling Plate Insertion

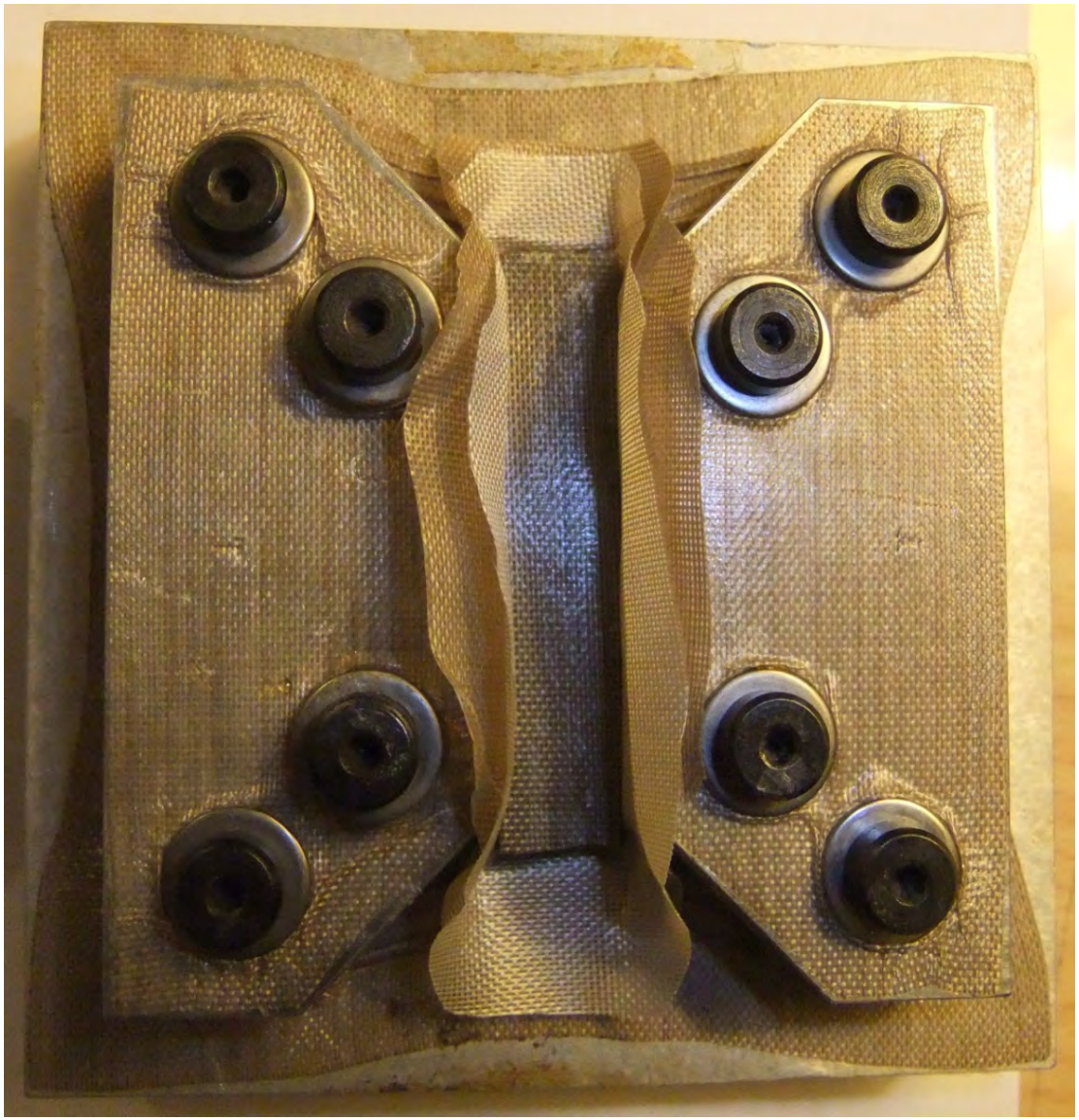


Figure BCF11, Bottom Graphite Tooling Plate Insertion Top View

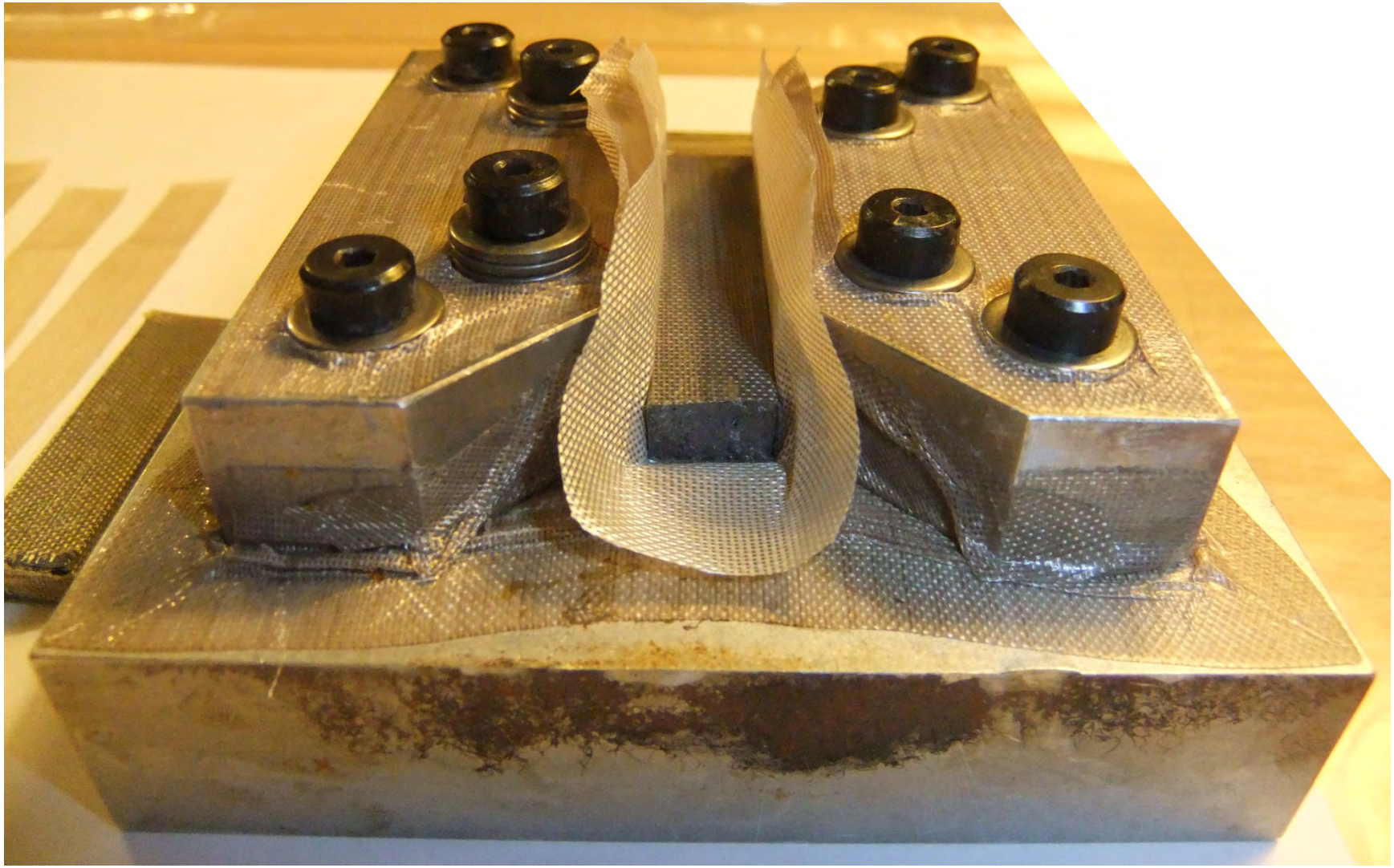


Figure BCF12, Bottom Graphite Tooling Plate Insertion Top Side View

4.7 Section 7: Bottom Tooling Plate Bleed Plies Insertion

Figure BCF13, Bottom Tooling Plate Bleed Plies Insertion Top Side View

4.8 Section 8: Fiber Tow Bundle Lay Up

Figure BCF14, Fiber Tow Bundle Lay Up Top View

4.9 Section 9: Top Tooling Plate Bleed Plies Insertion

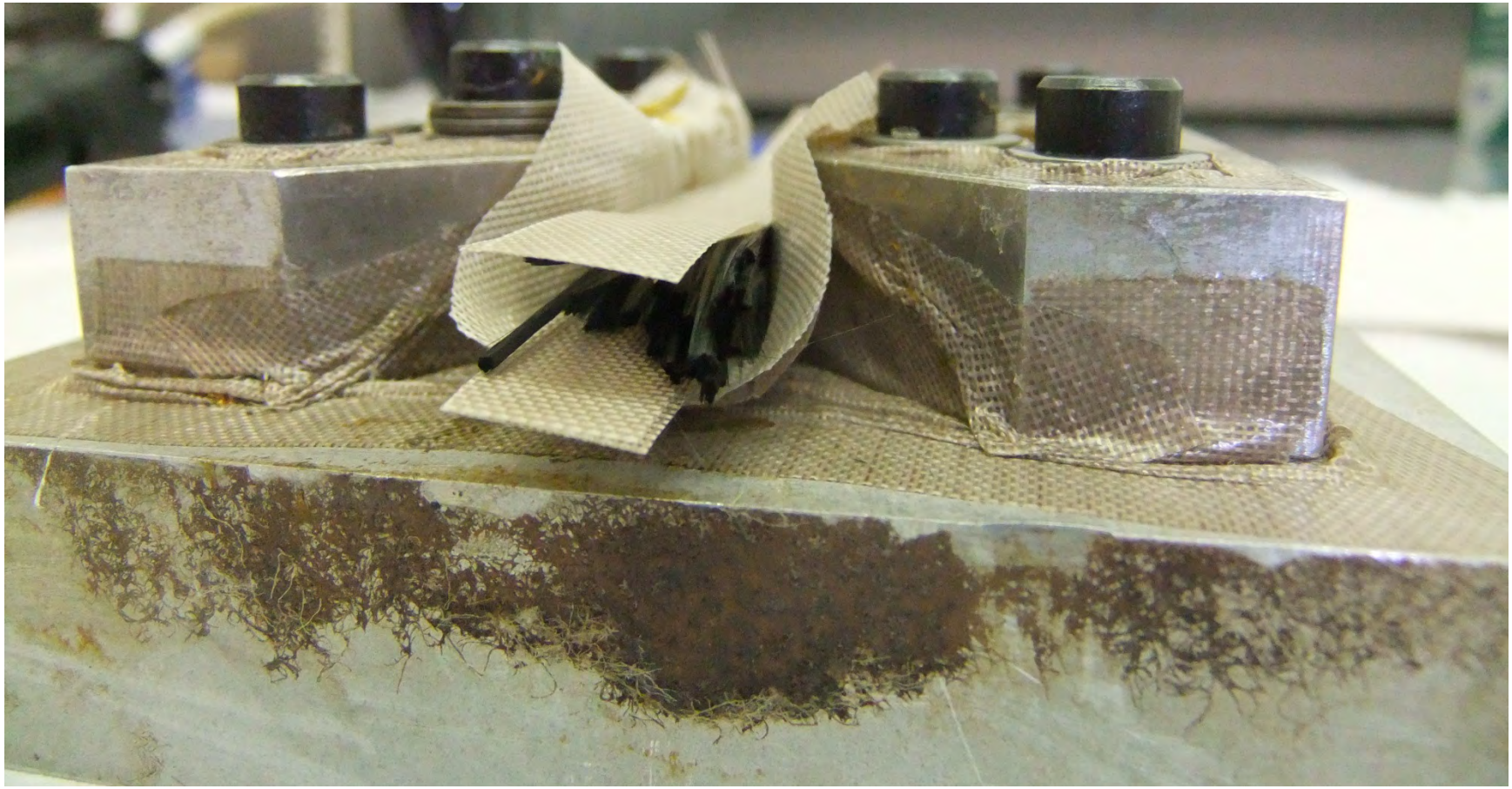


Figure BCF15, Top Tooling Plate Bleed Plies Insertion Side View

4.10 Section 10: Top Graphite Tooling Plate Insertion

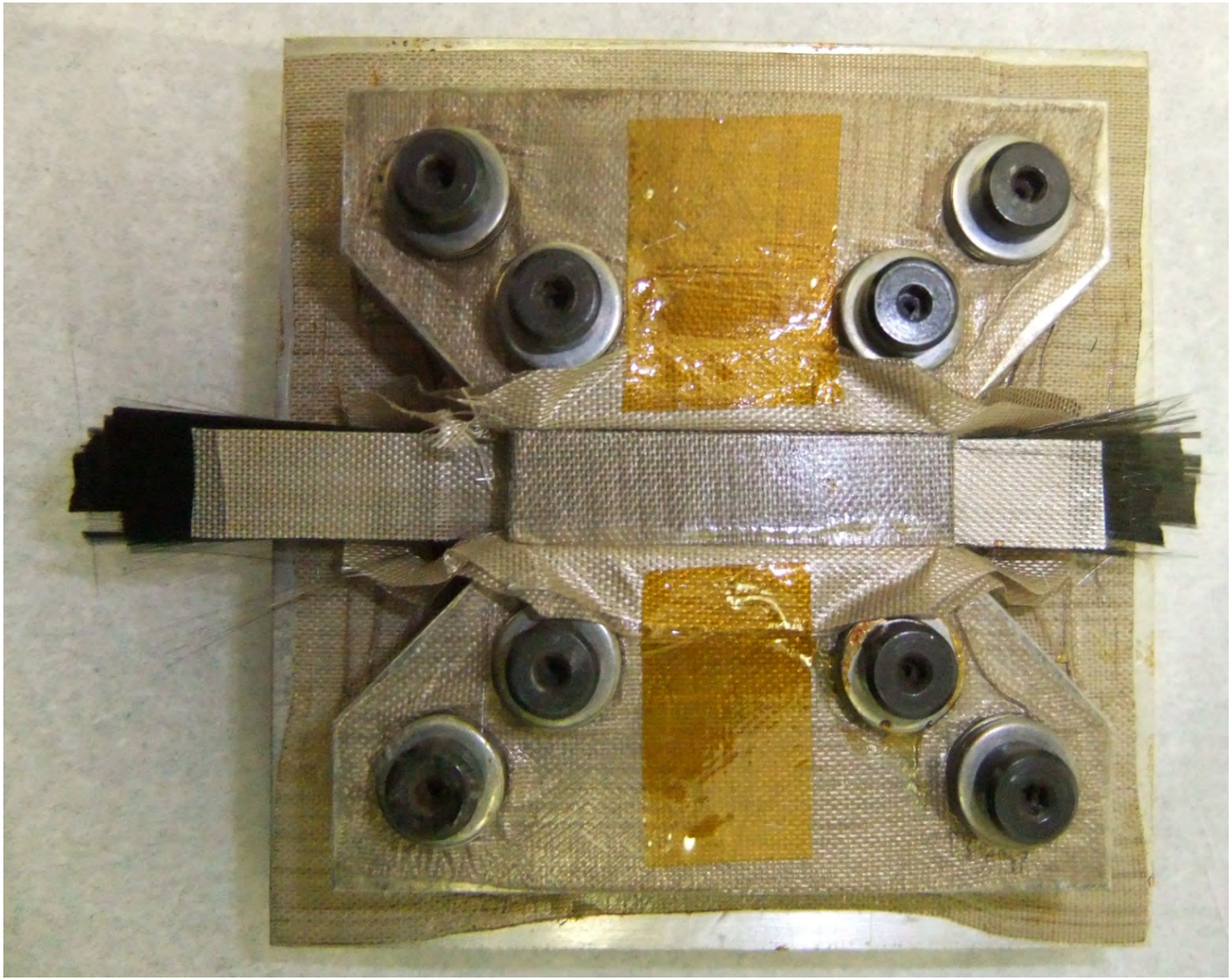


Figure BCF16, Top Graphite Tooling Plate Insertion Top View

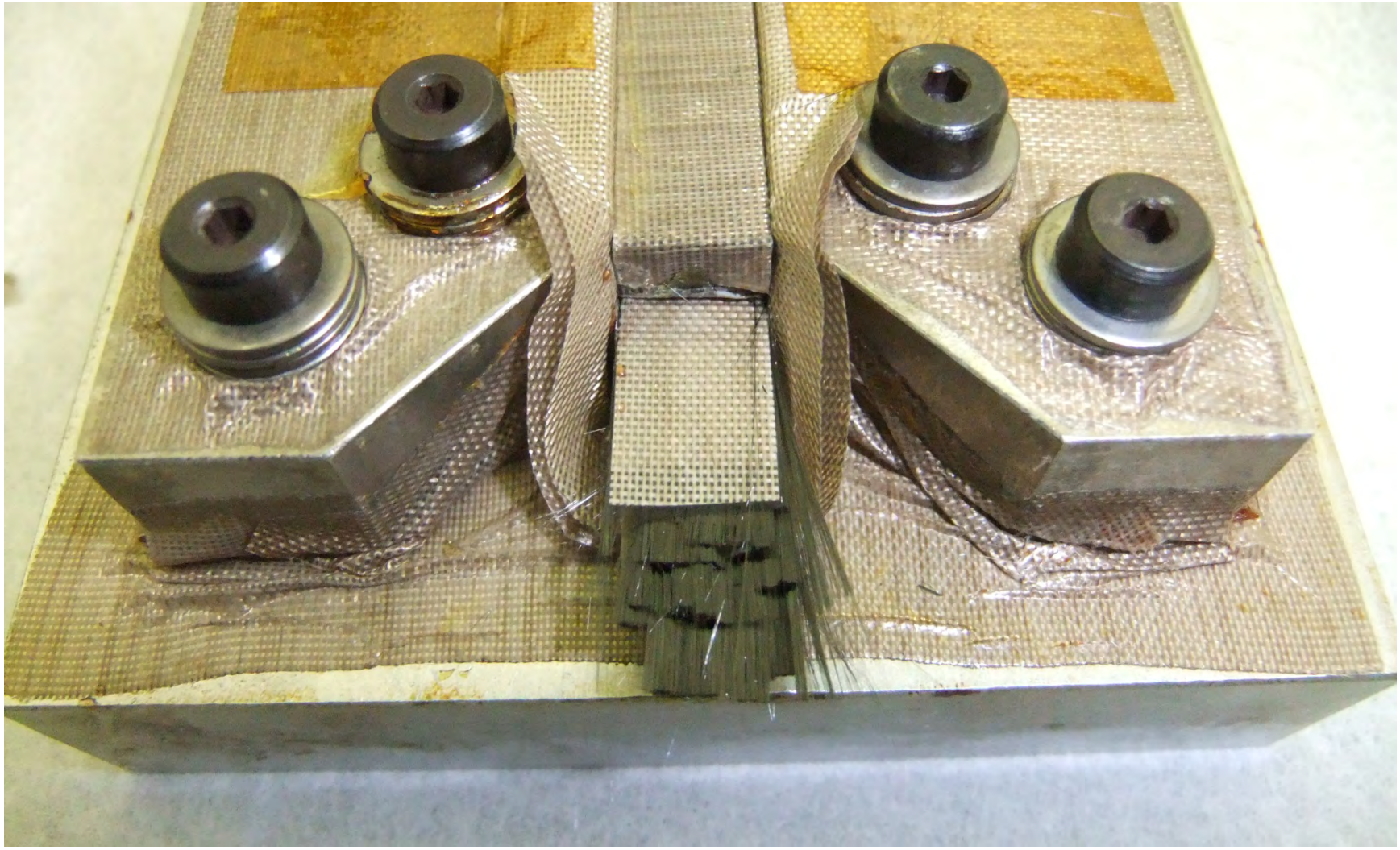


Figure BCF17, Top Graphite Tooling Plate Insertion Top Side View

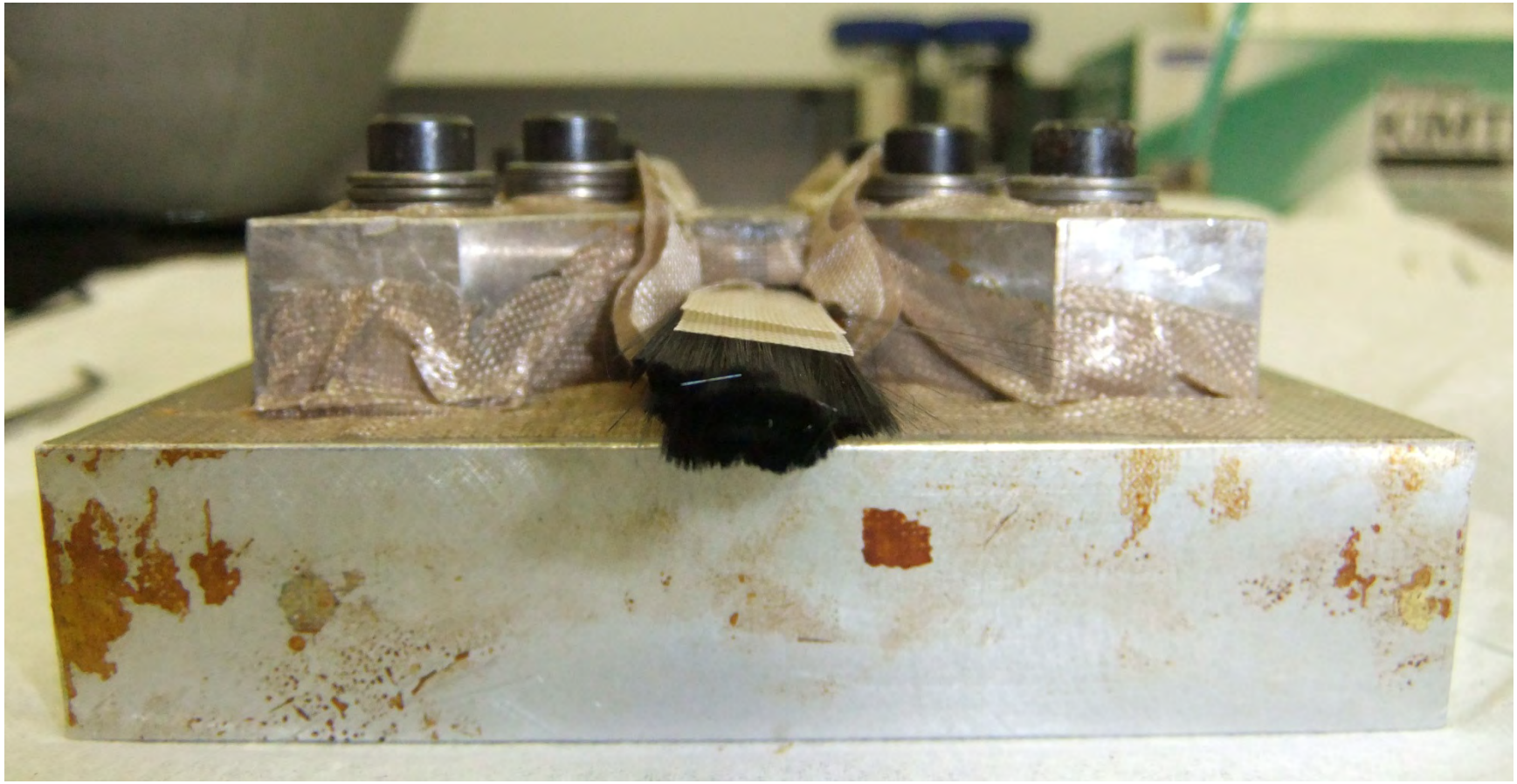


Figure BCF18, Top Graphite Tooling Plate Insertion Left Side View

4.11 Section 11: Trim Excess Fibers

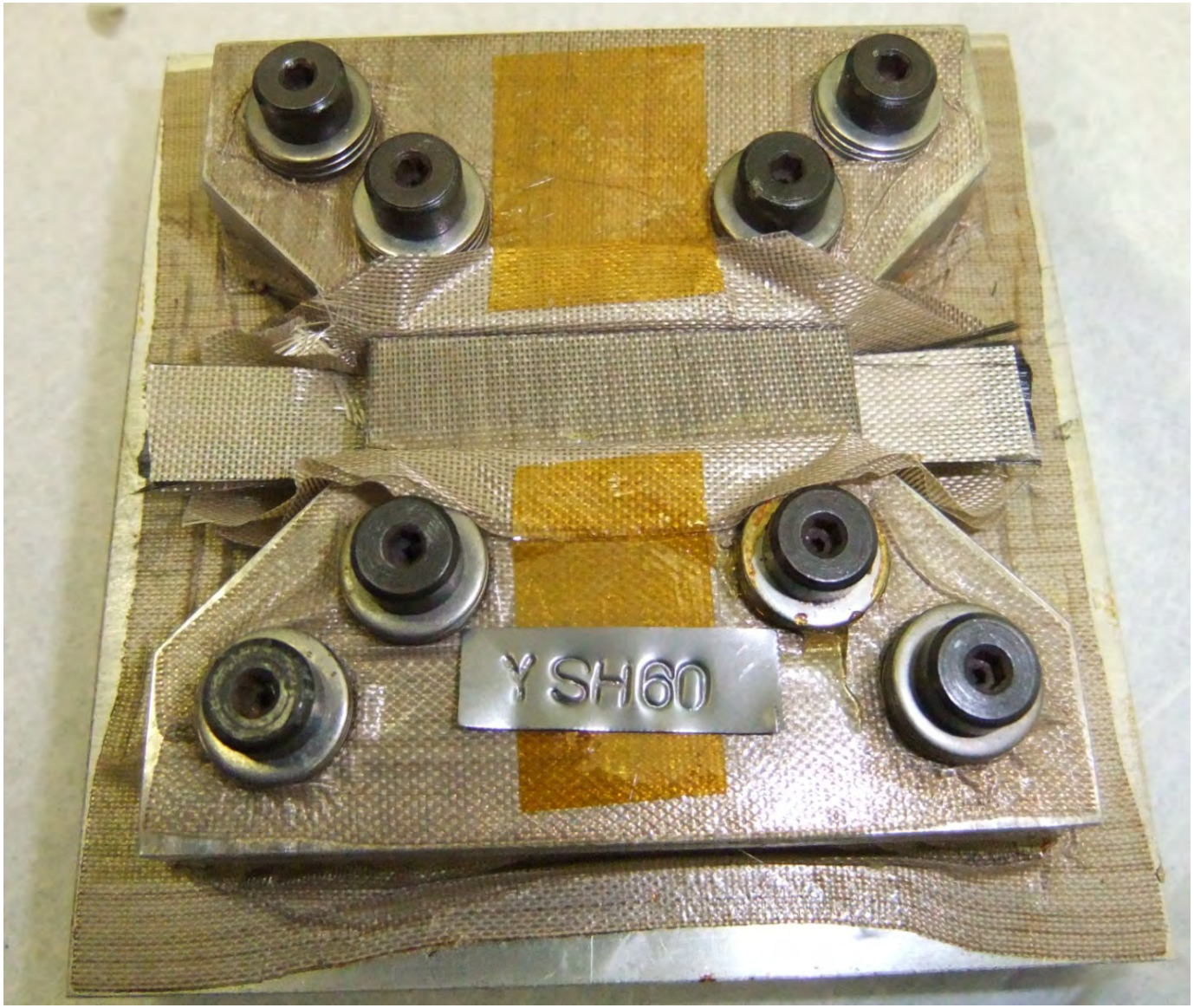


Figure BCF19, Trimming Excess YSH Type Fibers Top View

4.12 Section 12: Refrigerated Composite Lay Up Storage Prior To Cure

Figure BCF20, Refrigerated Composite Lay Up Storage Prior To Cure

4.13 Section 13: Bulk Composite Specimen Fabrication & Cure Experimental Run 2 (ER2)

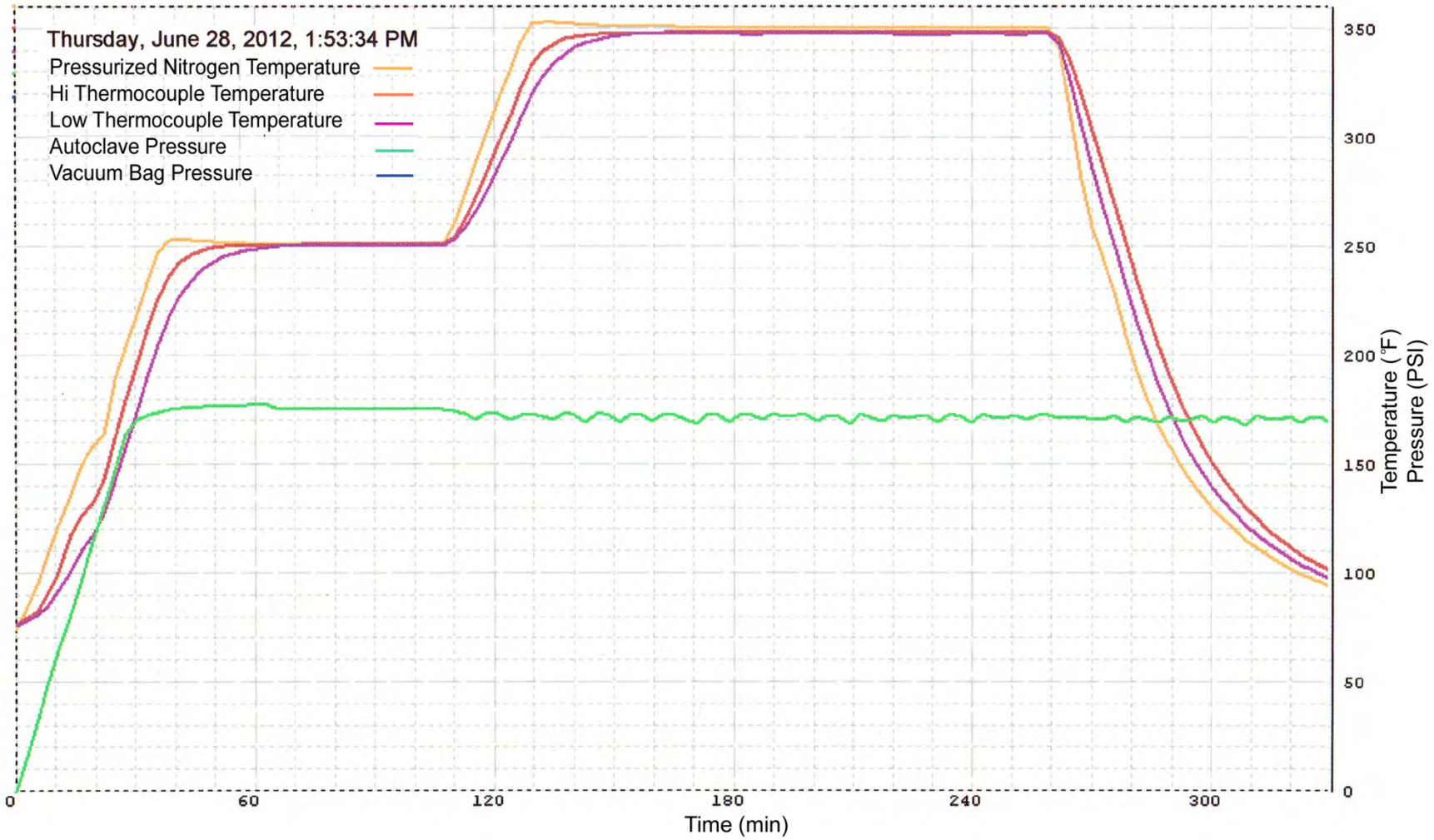


Figure BCF21, Composite Cure Profile

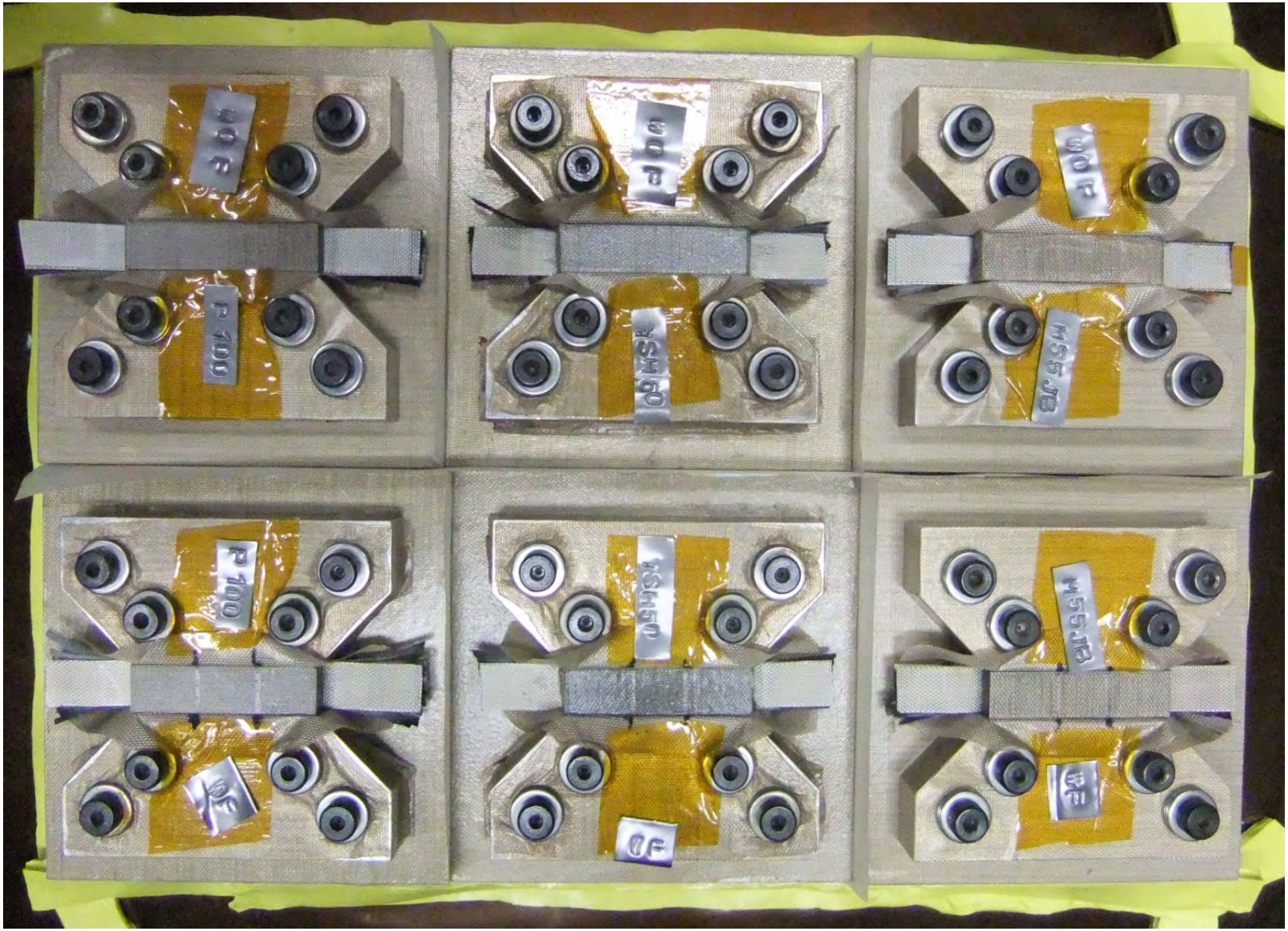


Figure BCF22, Composite Bagging I
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins

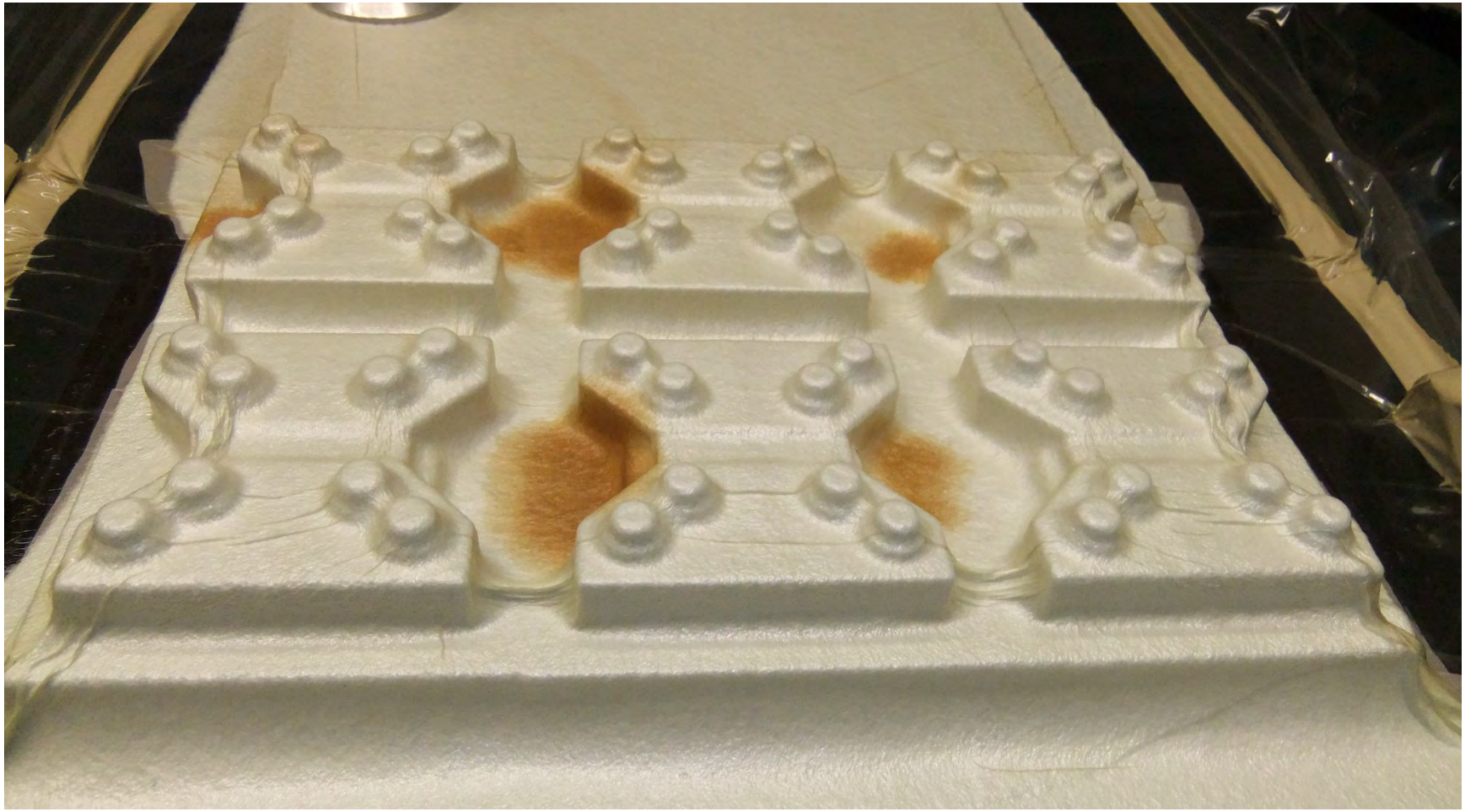


Figure BCF23, Cured Bagged Composite

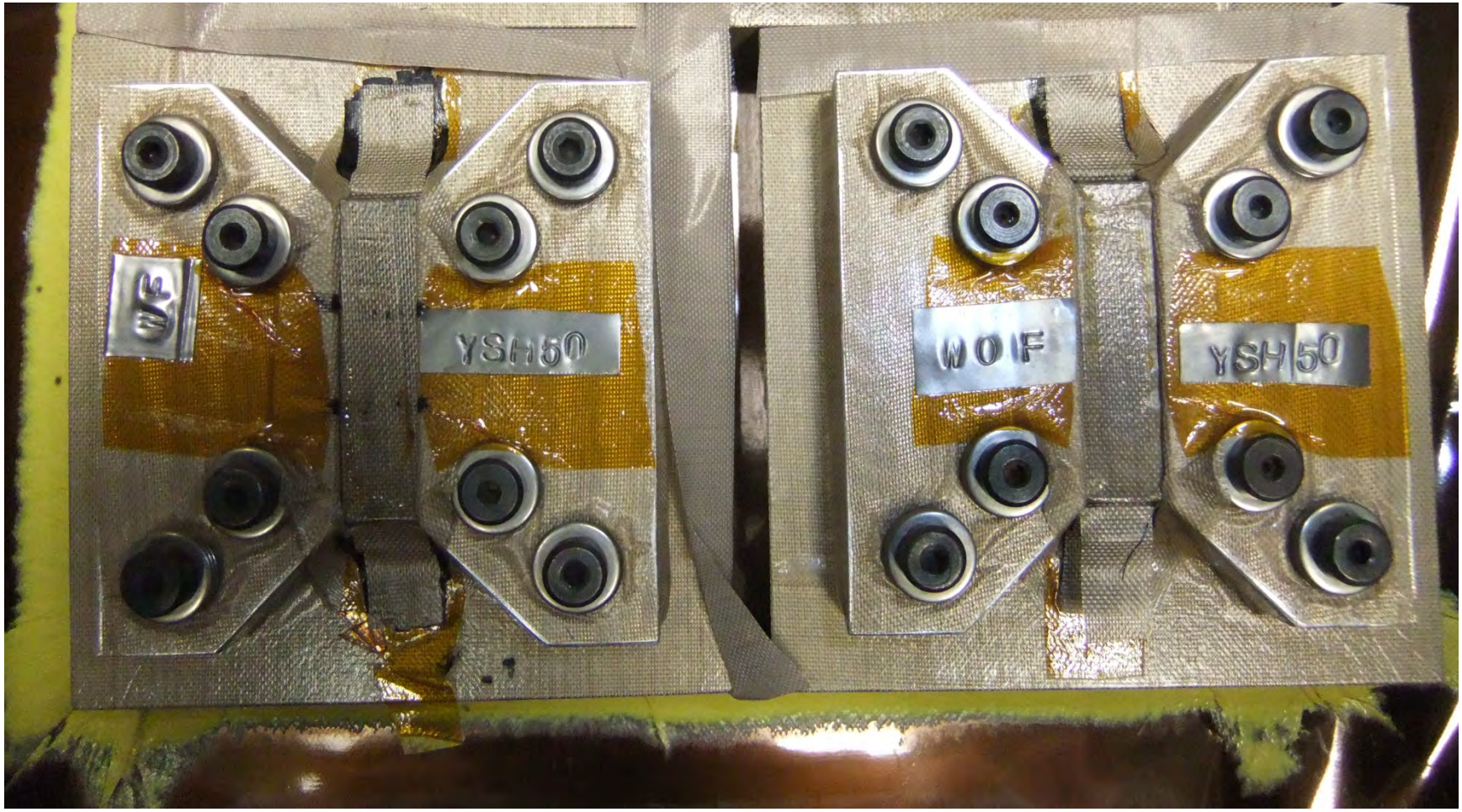
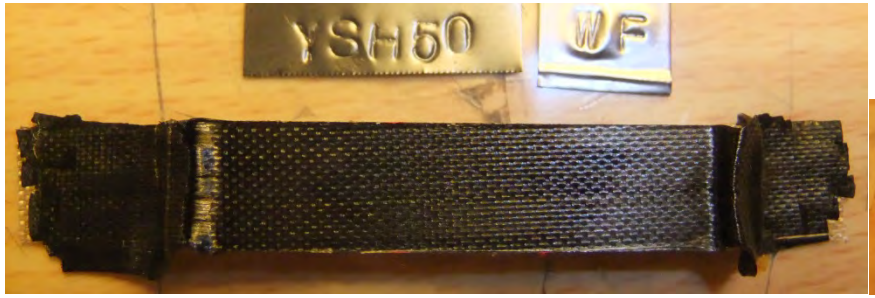
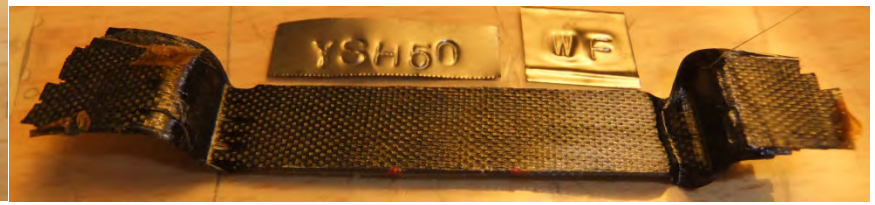


Figure BCF24, Cured DeBagged YSH50A Bulk Composite Specimens
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins



Top View



Side-Edge View

Bottom View I

Bottom View II

Figure BCF25, Bulk YSH50A Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) YSH50A fibers/tows
Note: Zone between red marks locates fibers with continuous graphite fins

Bottom View I

Top View

Bottom Side View

Edge View

Figure BCF26, Bulk YSH50A Composite Specimens made with baseline YSH50A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

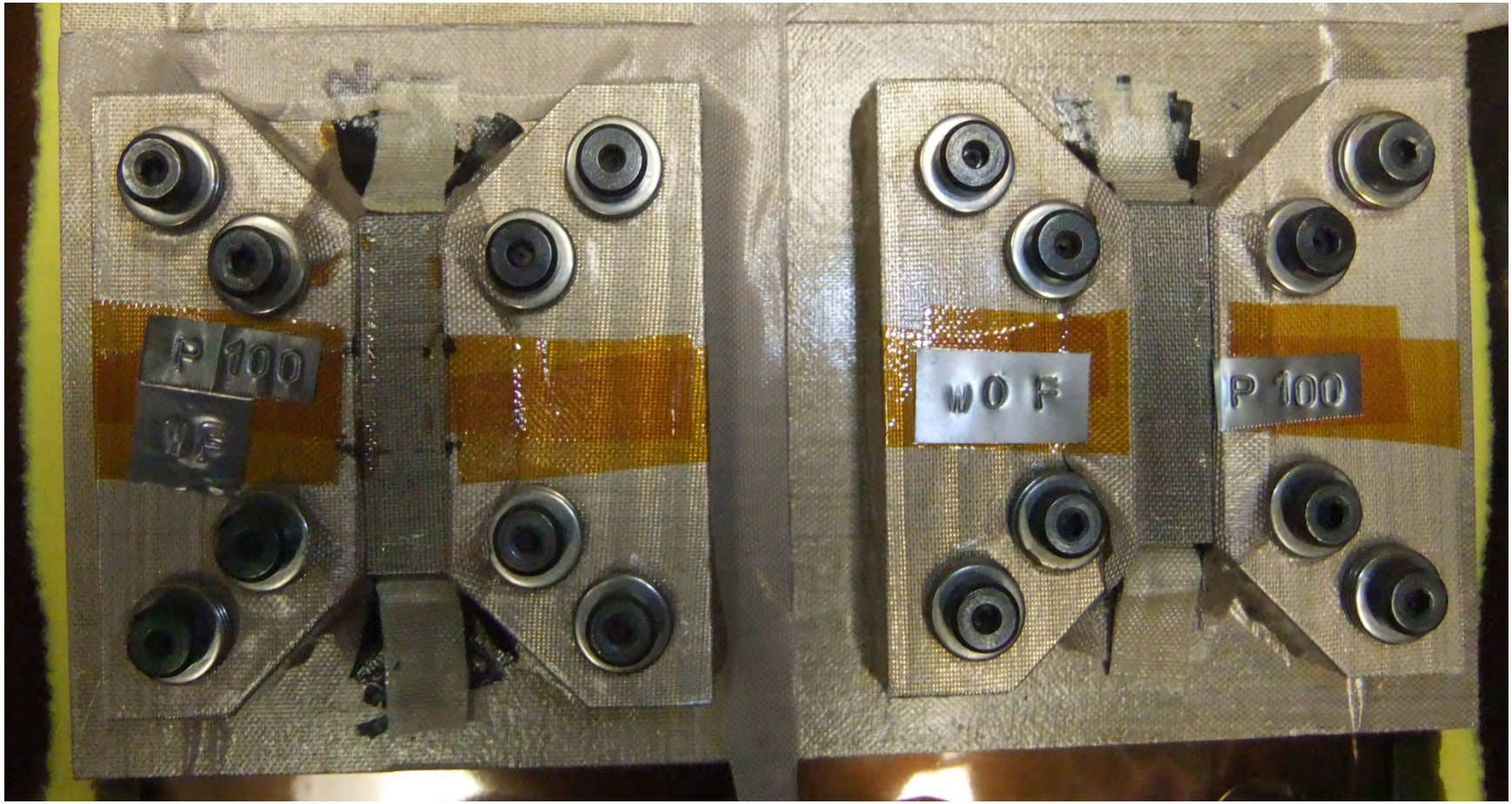
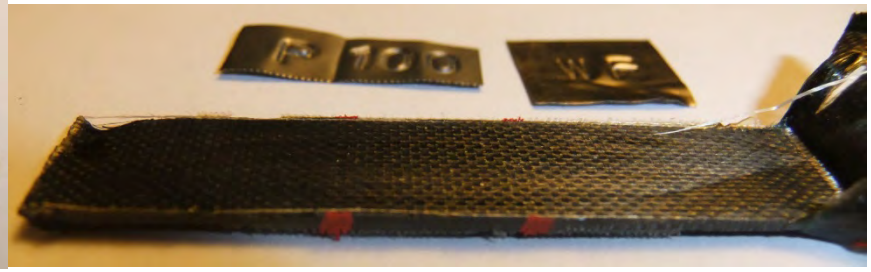
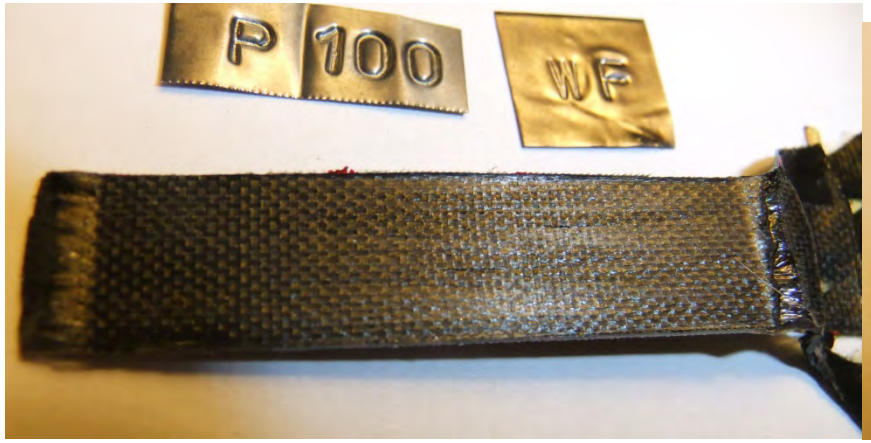


Figure BCF27, Cured DeBagged P100S Bulk Composite Specimens
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins

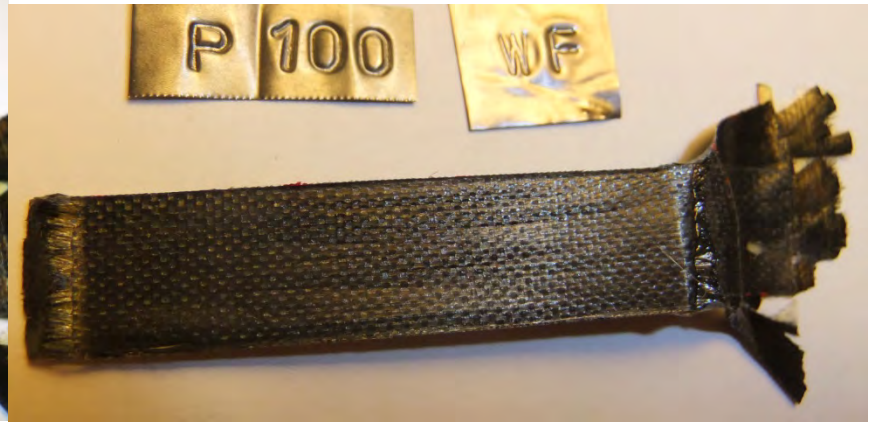
Bottom View



Side-Edge View

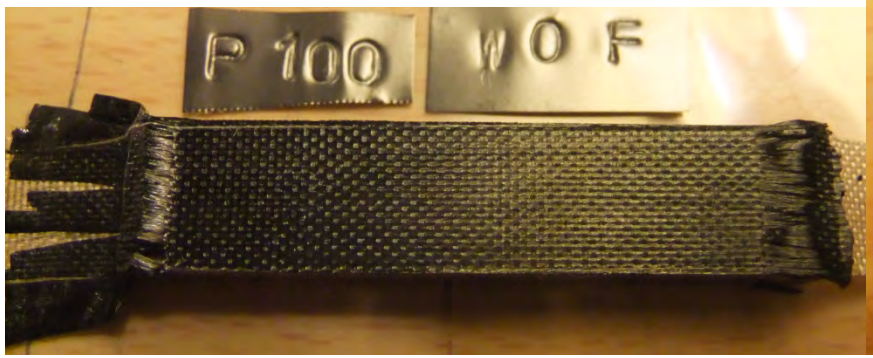


Top View I



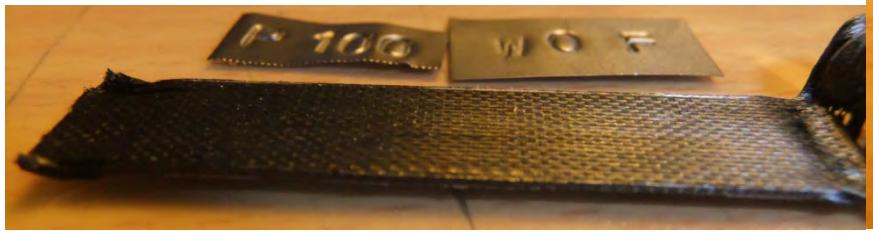
Top View II

Figure BCF28, Bulk P100S Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) P100S fibers/tows
Note: Zone between red marks locates fibers with continuous graphite fins

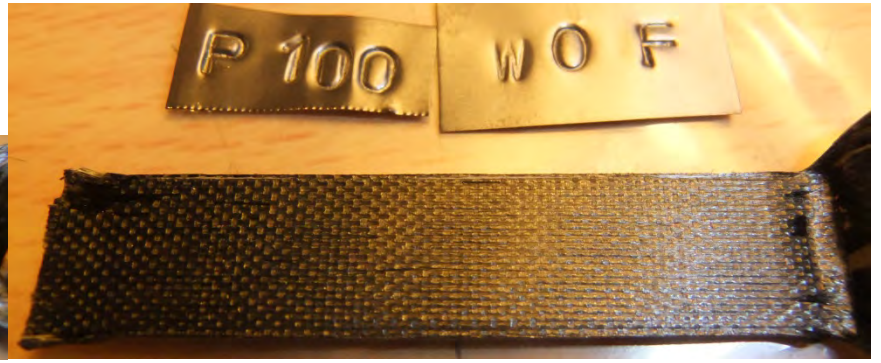


Top View

Bottom View I



Edge View



Bottom View II

Figure BCF29, Bulk P100S Composite Specimens made with baseline P100S fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

4.14 Section 14: Bulk Composite Specimen Fabrication & Cure Experimental Run 3 (ER3)

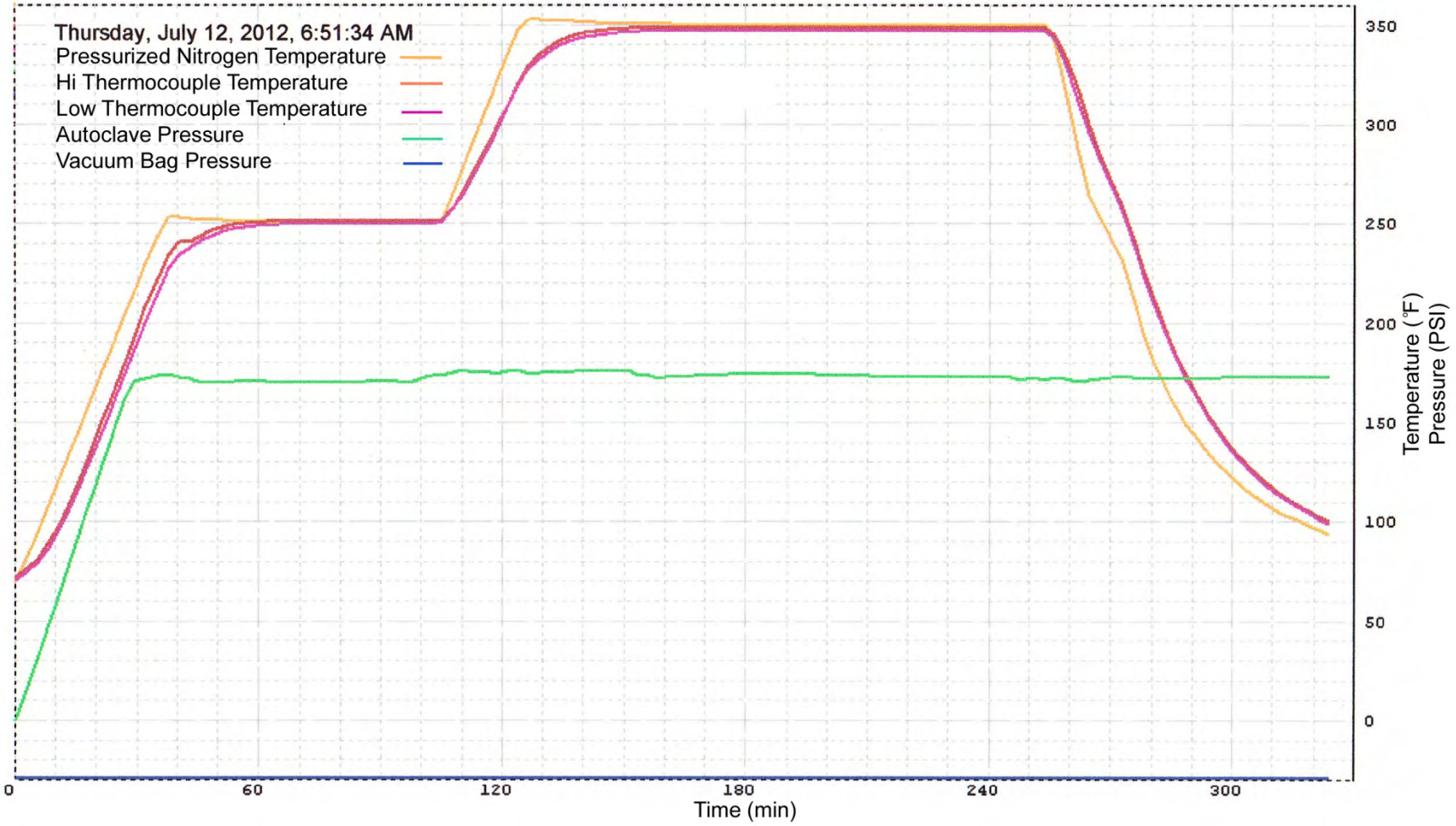


Figure BCF30, Composite Cure Profile

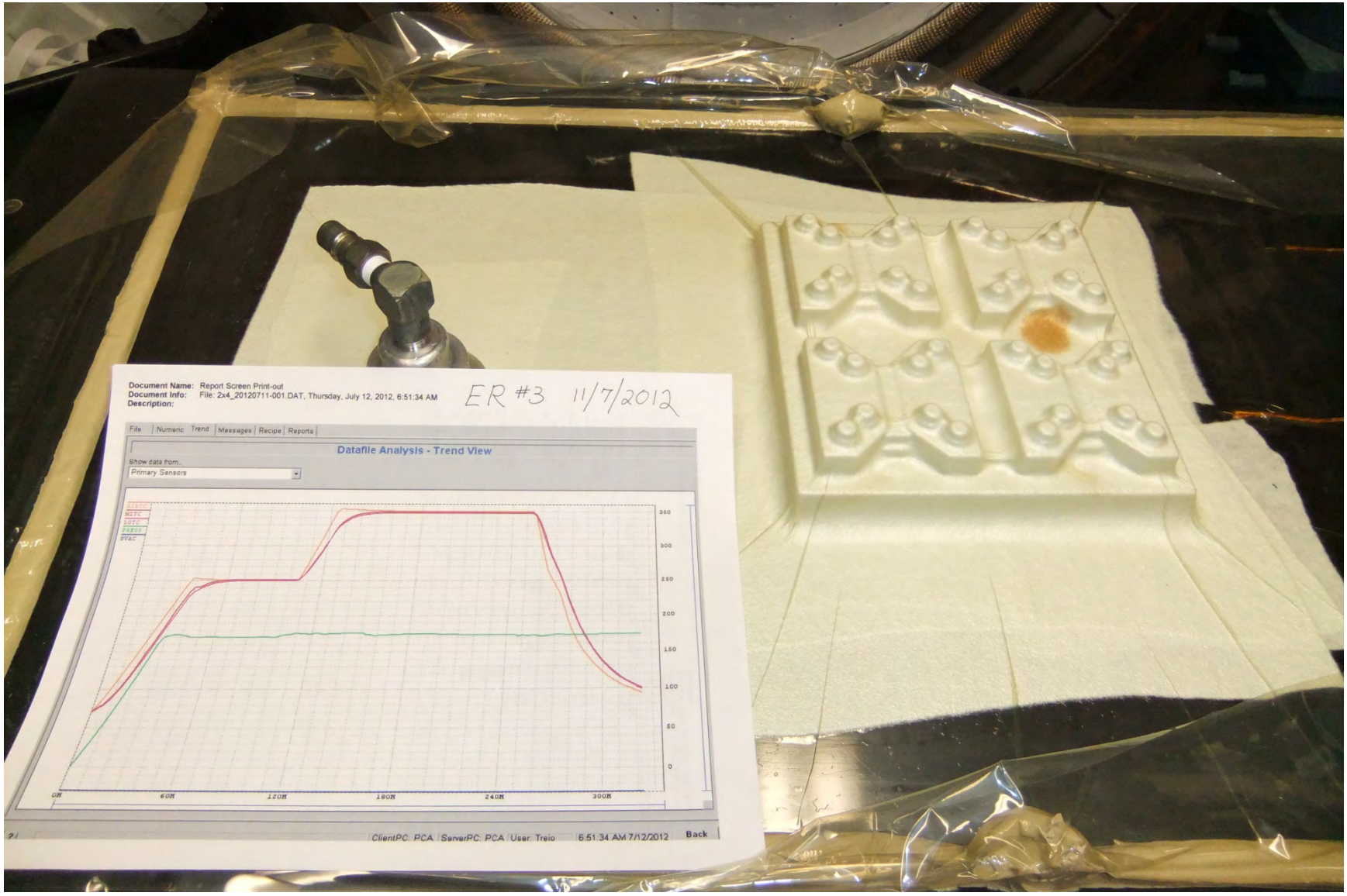


Figure BCF31, Cured Bagged Composite

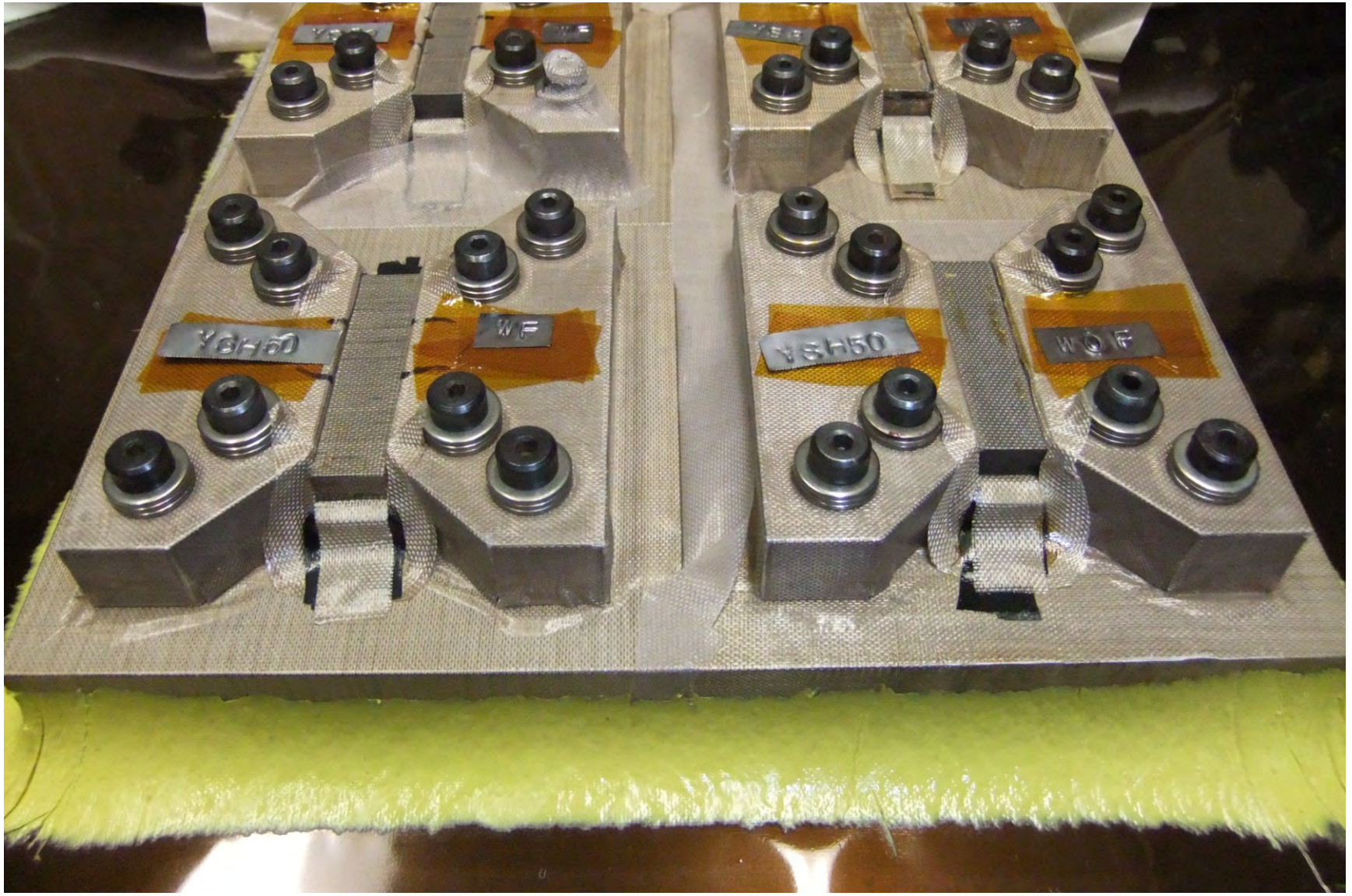
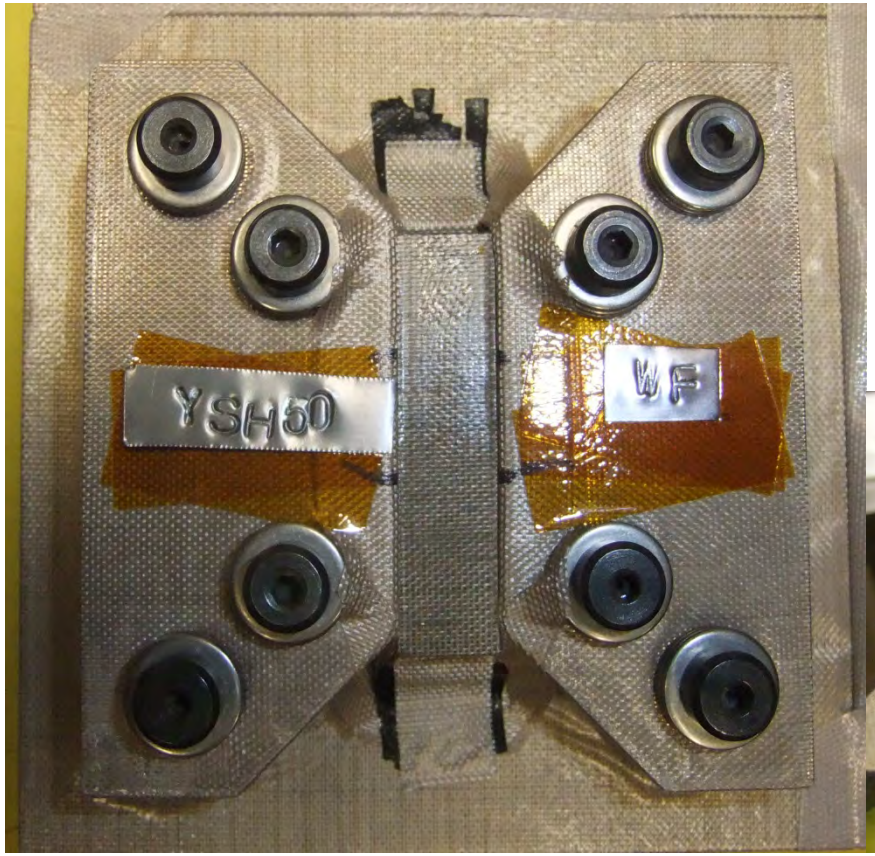
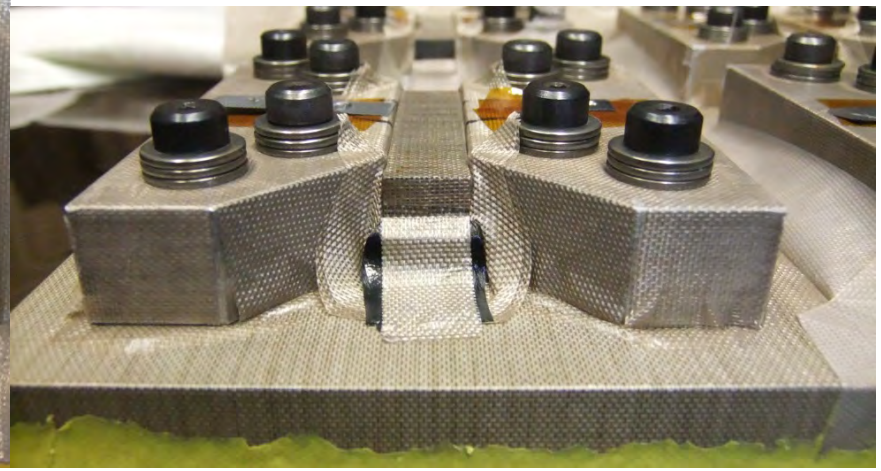


Figure BCF32, Cured DeBagged Bulk Composite Specimens
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins



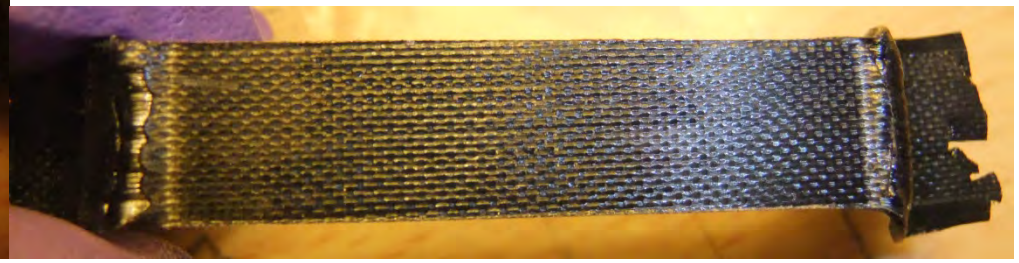
Top View



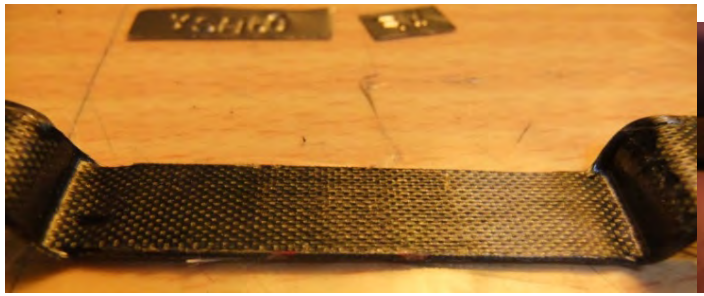
Side View

Figure BCF33, Cured DeBagged Bulk YSH50A Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) YSH50A fibers/tows
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins

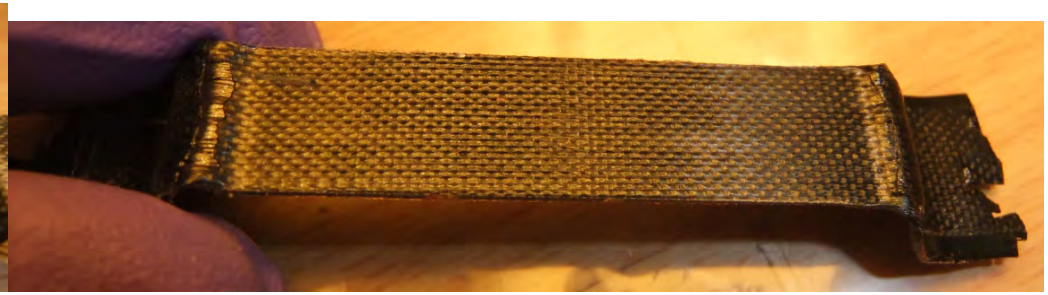
Bottom View I



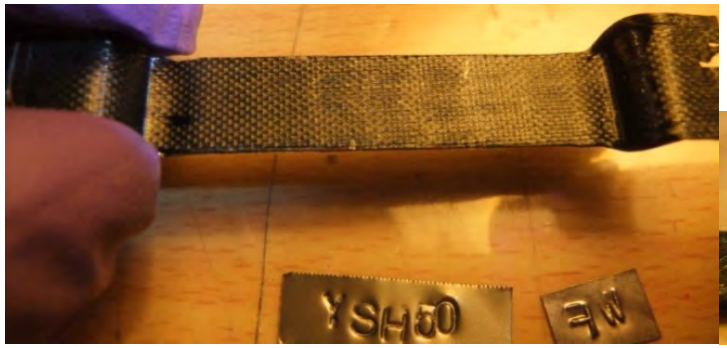
Top View I



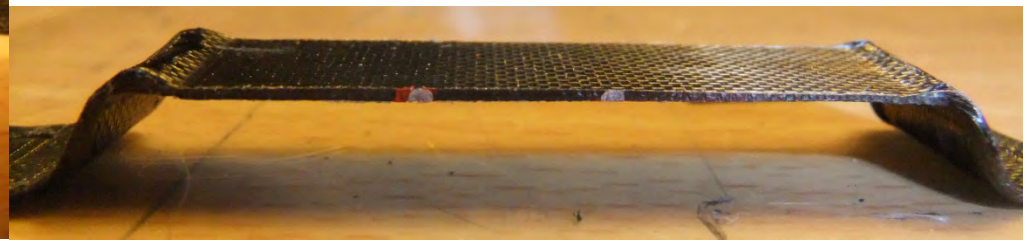
Bottom View II



Top View II

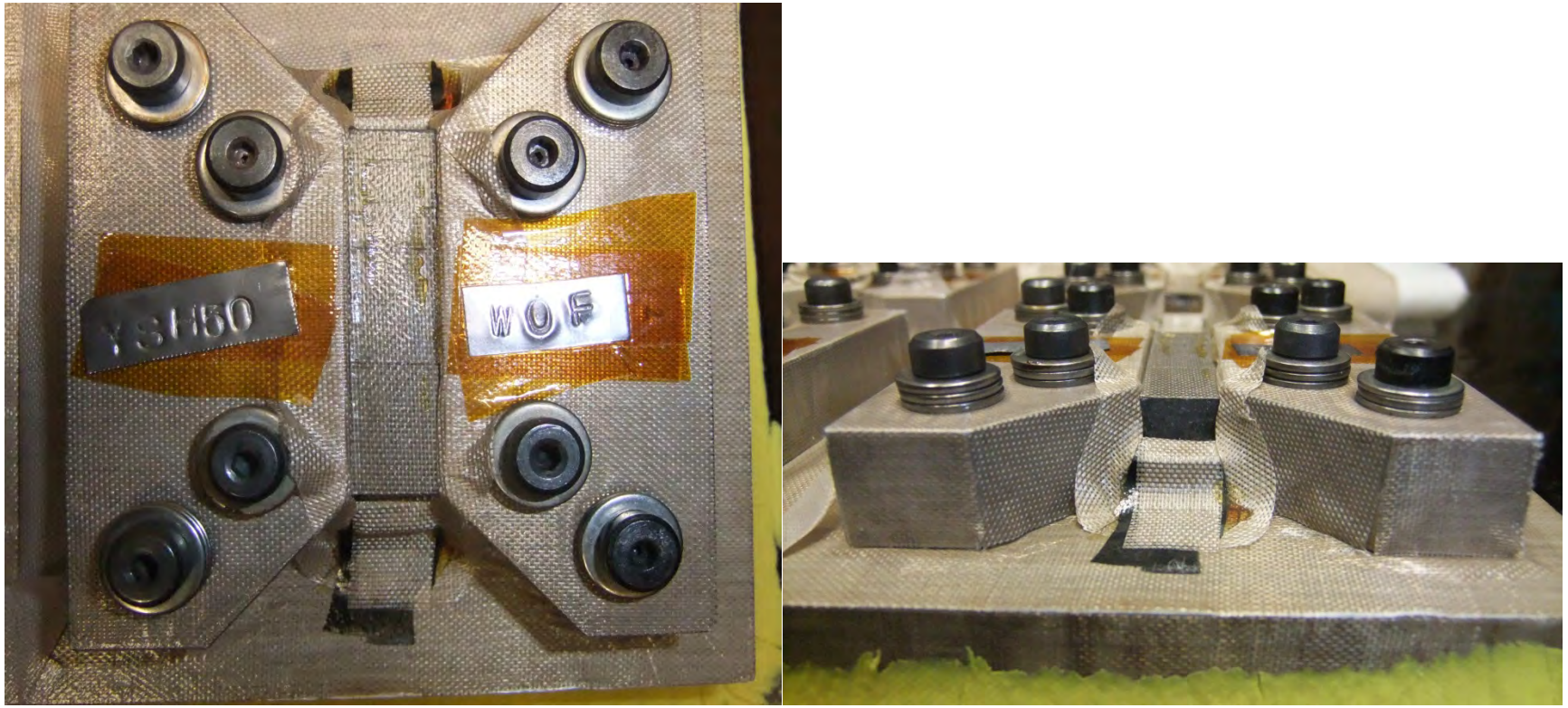


Bottom View III



Side-Edge View

Figure BCF34, Bulk YSH50A Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) YSH50A fibers/tows
Note: Zone between silver-red marks locates fibers with continuous graphite fins

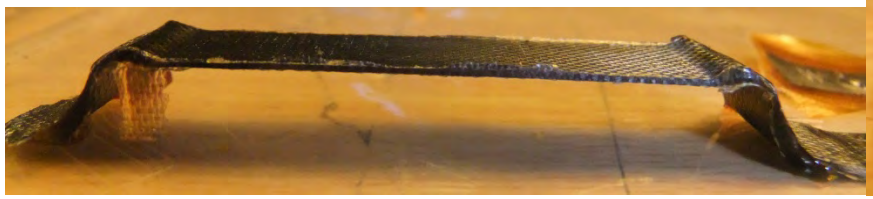


Top View Side View

Figure BCF35, Cured DeBagged Bulk YSH50A Composite Specimens made with baseline YSH50A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

Bottom View

Top View I

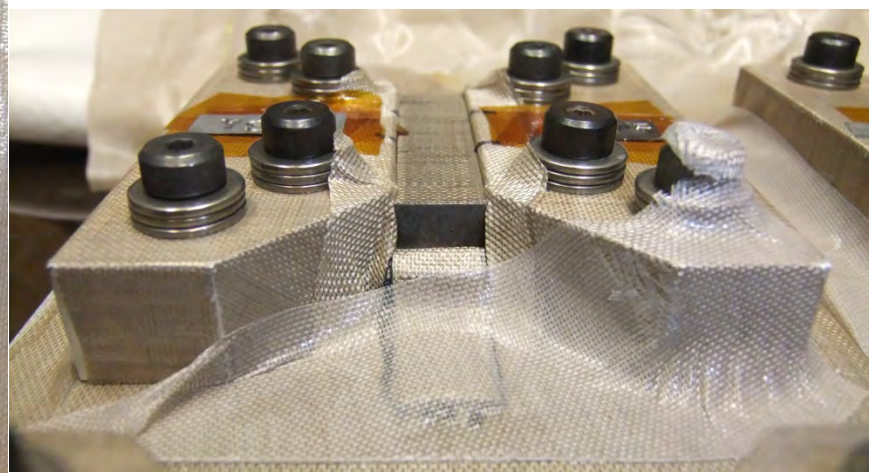


Edge View

Top View II

Figure BCF36, Bulk YSH50A Composite Specimens made with baseline YSH50A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

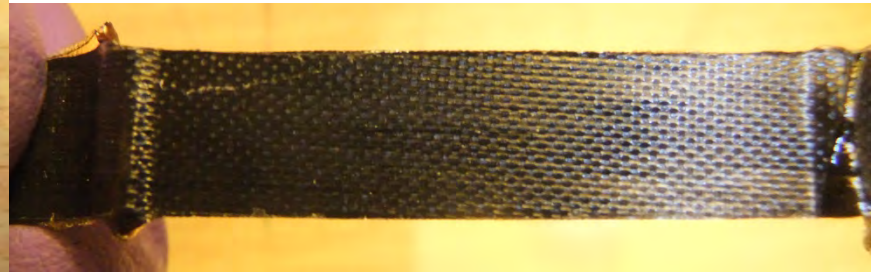
Top View



Side View

Figure BCF37, Cured DeBagged Bulk YS80A Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) YS80A fibers/tows
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins

Bottom View I

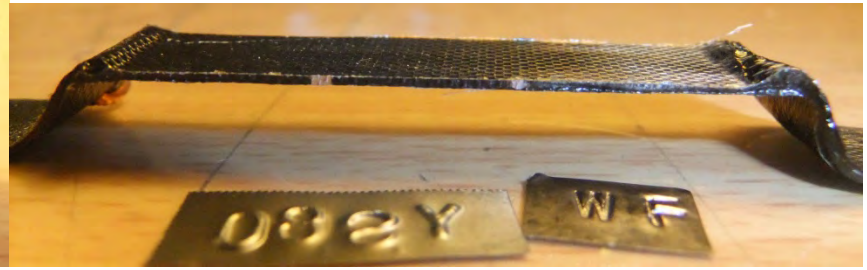


Top View I

Bottom View II

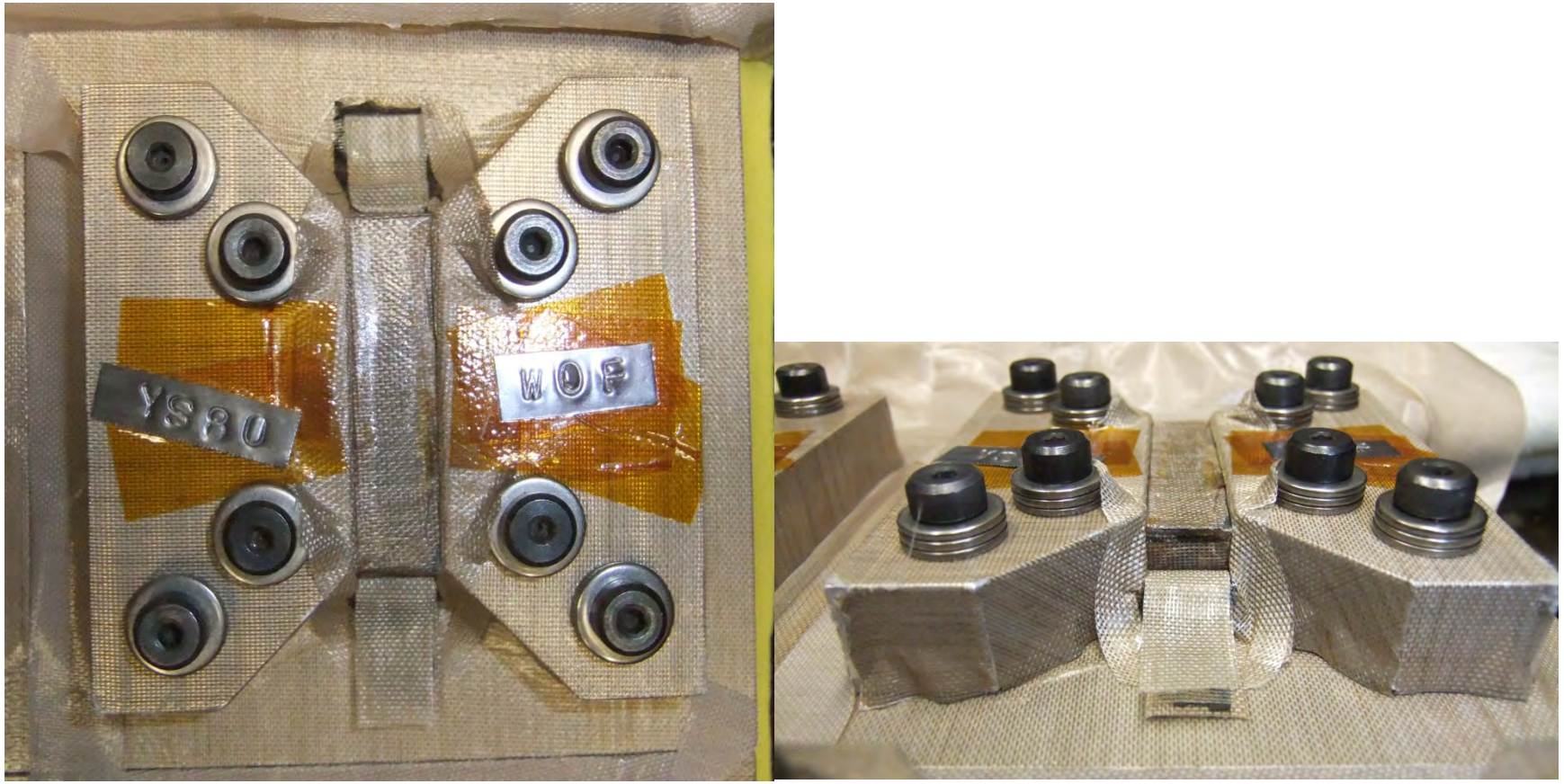
Top View II

Bottom View III



Side-Edge View

Figure BCF38, Bulk YS80A Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) YS80A fibers/tows
Note: Zone between silver marks locates fibers with continuous graphite fins



Top View Side View

Figure BCF39, Cured DeBagged Bulk YS80A Composite Specimens made with baseline YS80A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

Top View

Bottom View

Edge Top View

Edge Bottom View

Figure BCF40, Bulk YS80A Composite Specimens made with baseline YS80A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

168

4.15 Section 15: Bulk Composite Specimen Fabrication & Cure Experimental Run 4 (ER4)

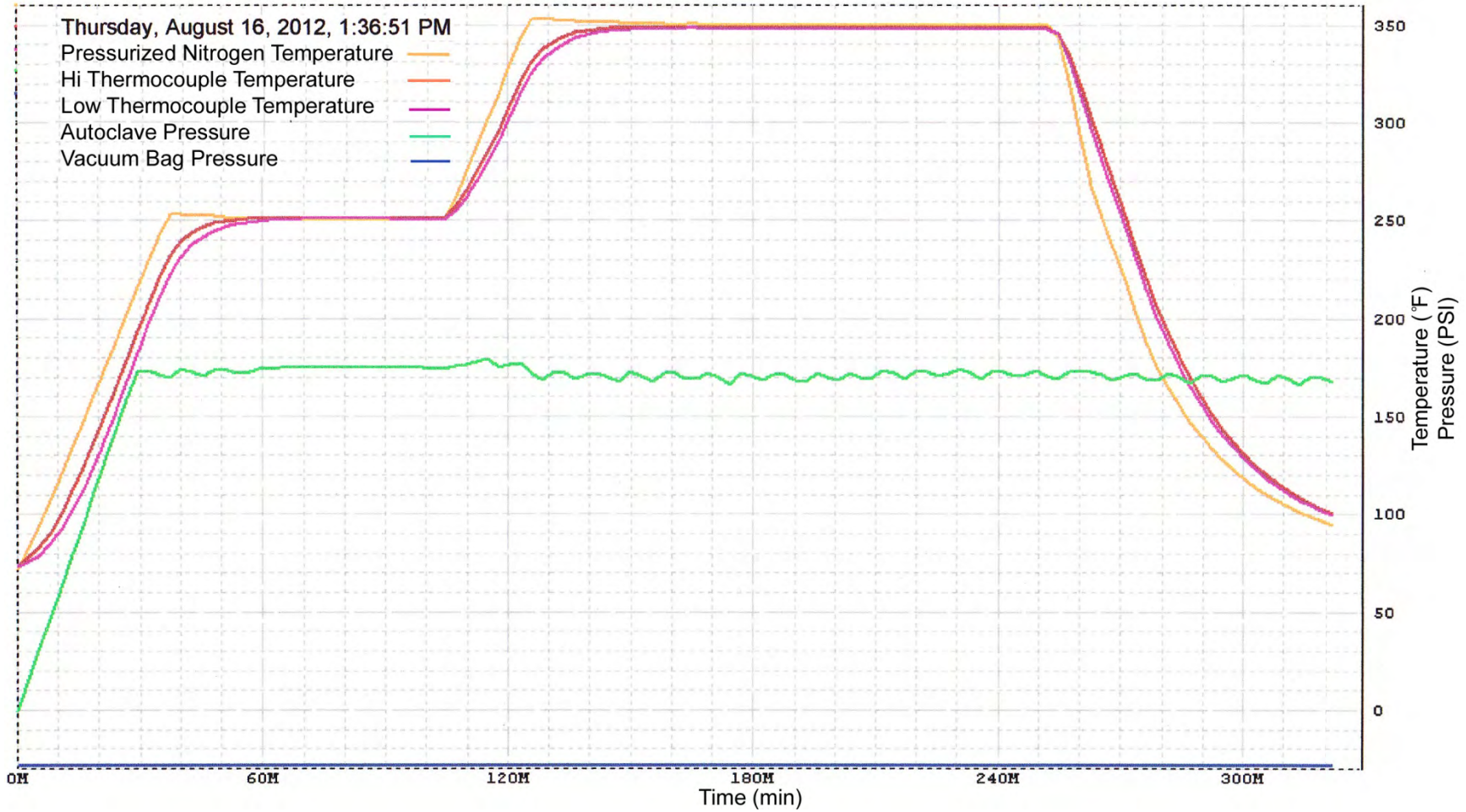
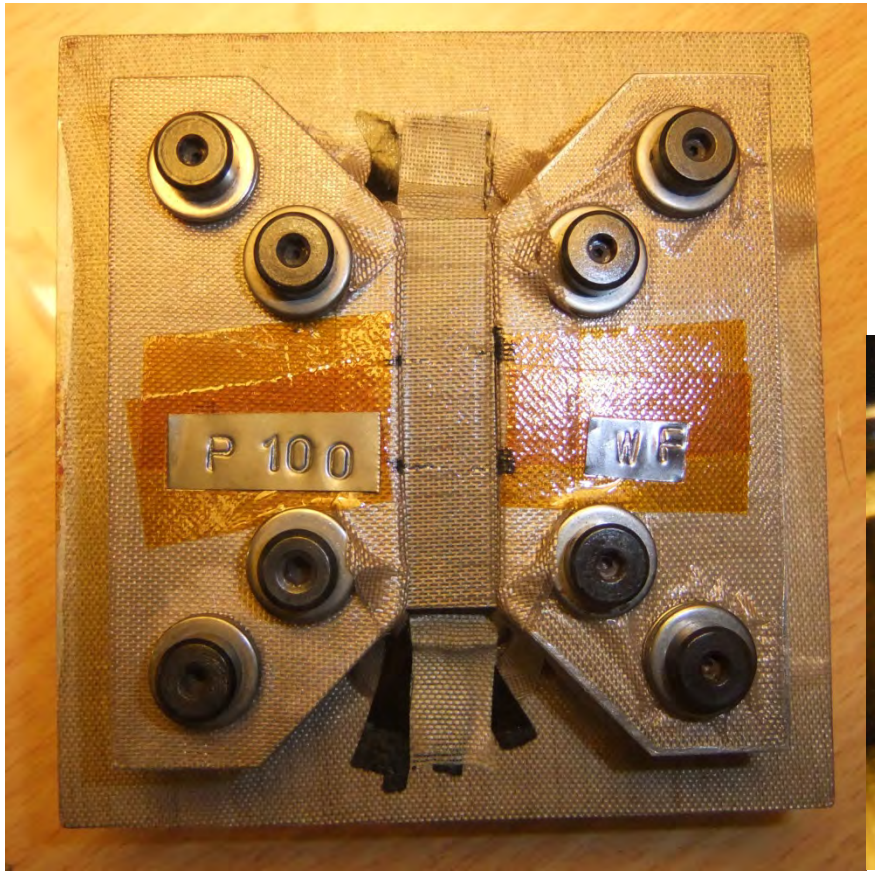


Figure BCF41, Composite Cure Profile



Top View

Side View

Figure BCF42, Cured DeBagged Bulk P100S Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) P100S fibers/tows
Note: Zone between black marks locates laid up fiber tows exhibiting continuous graphite fins

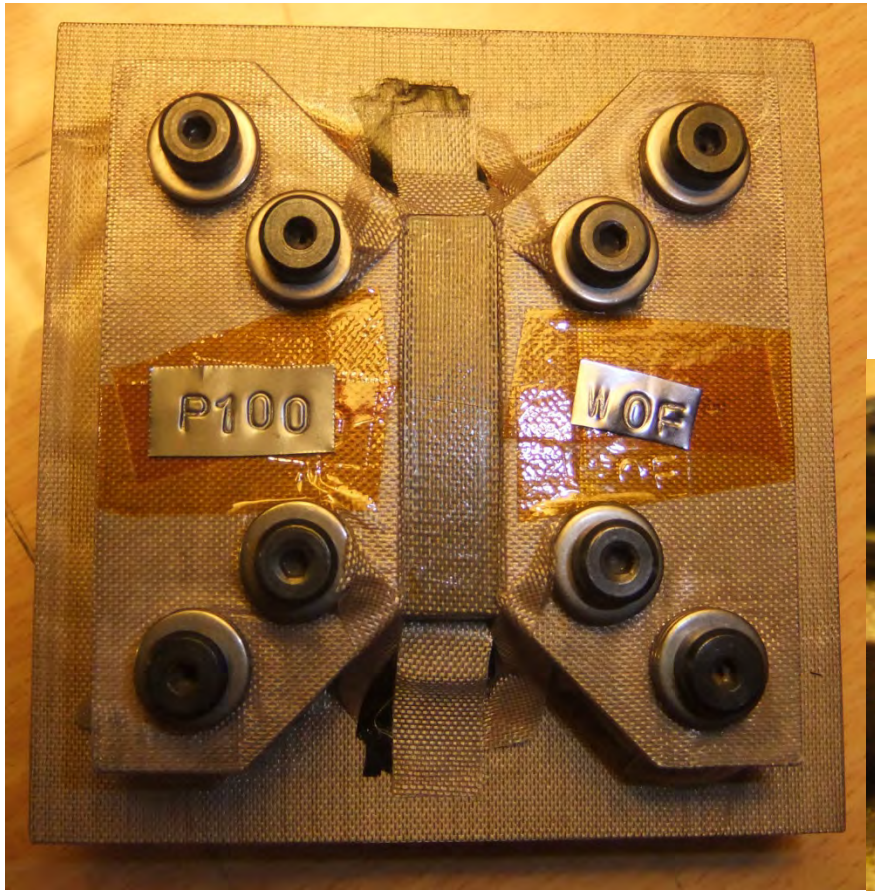
Bottom View I

Top View I

Bottom View II

Top Side-Edge View

Figure BCF43, Bulk P100S Composite Specimens made **W**ith contiguous graphite **F**ins exhibiting (ie WF) P100S fibers/tows
Note: Zone between silver marks locates fibers with continuous graphite fins



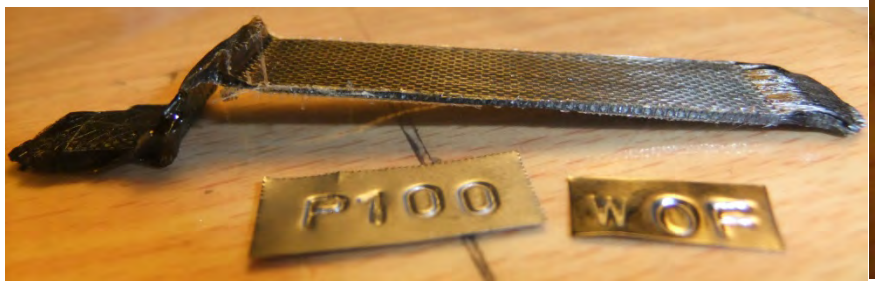
Top View

Side View

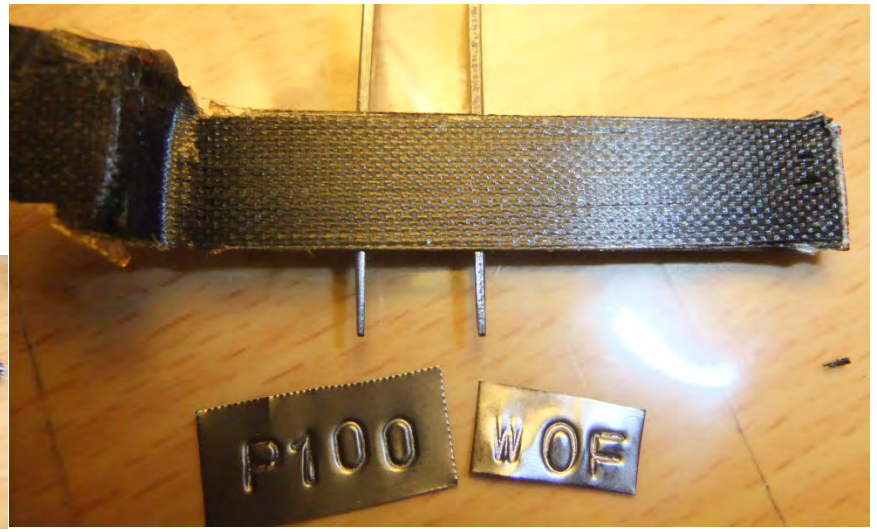
Figure BCF 44, Cured DeBagged Bulk P100S Composite Specimens made with baseline P100S fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

Top View

Bottom View I



Edge Top View



Bottom View II

Figure BCF45, Bulk P100S Composite Specimens made with baseline P100S fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

4.16 Section 16: Bulk Composite Specimen Fabrication & Cure Baseline Run 1 (BR1)

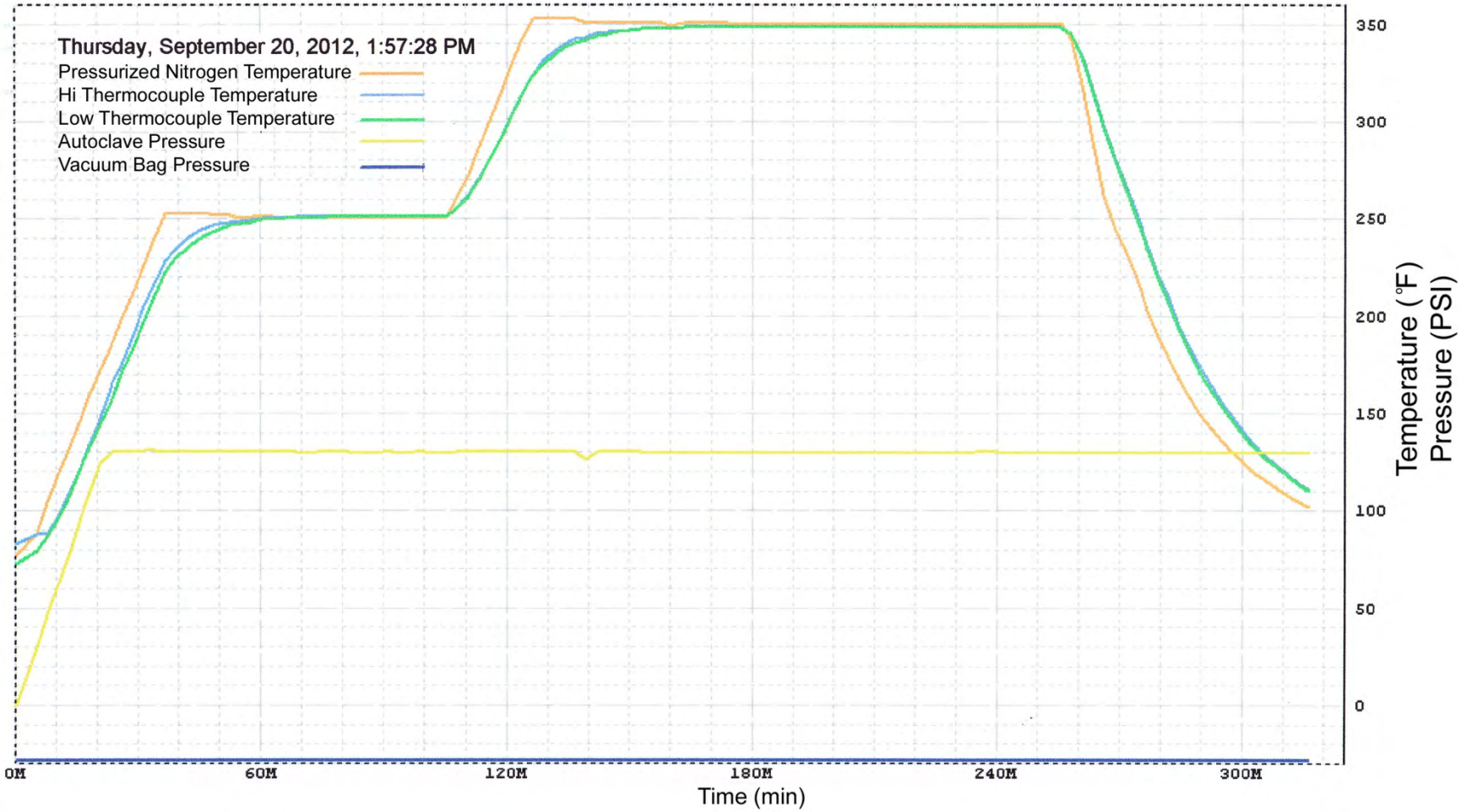


Figure BCF46, Composite Cure Profile

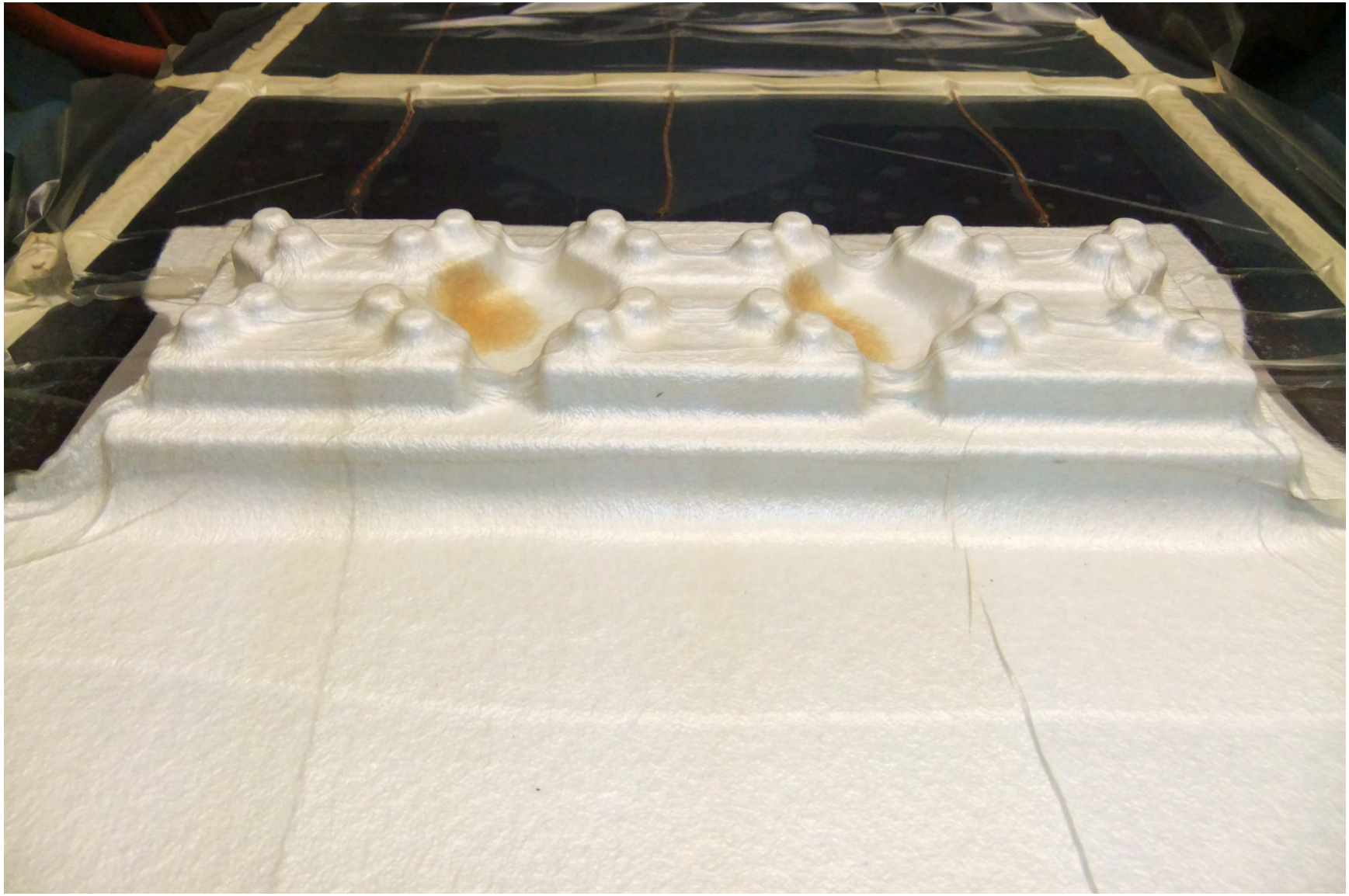
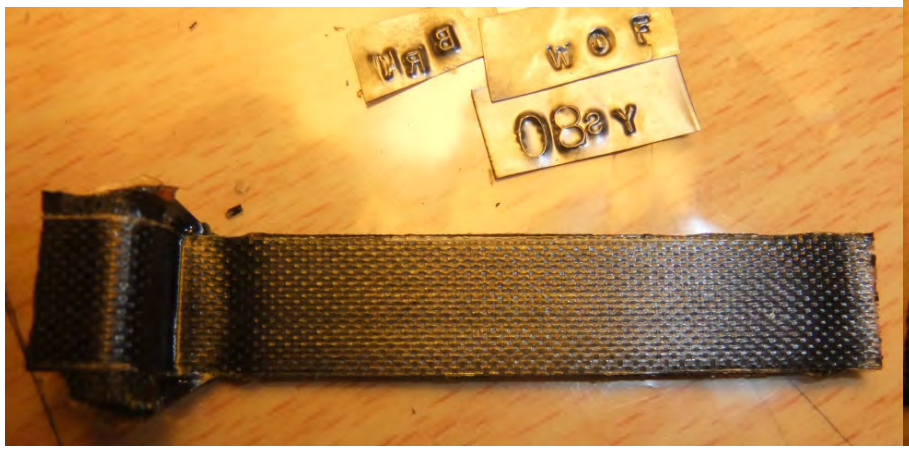


Figure BCF47, Cured Bagged Composite

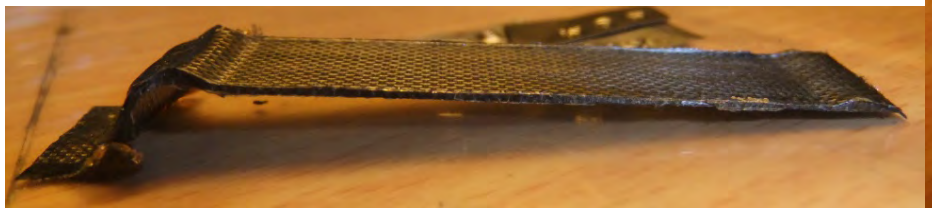
Top View Side View

Figure BCF48, Cured DeBagged Bulk YS80A Composite Specimens made with baseline YS80A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)



Bottom View

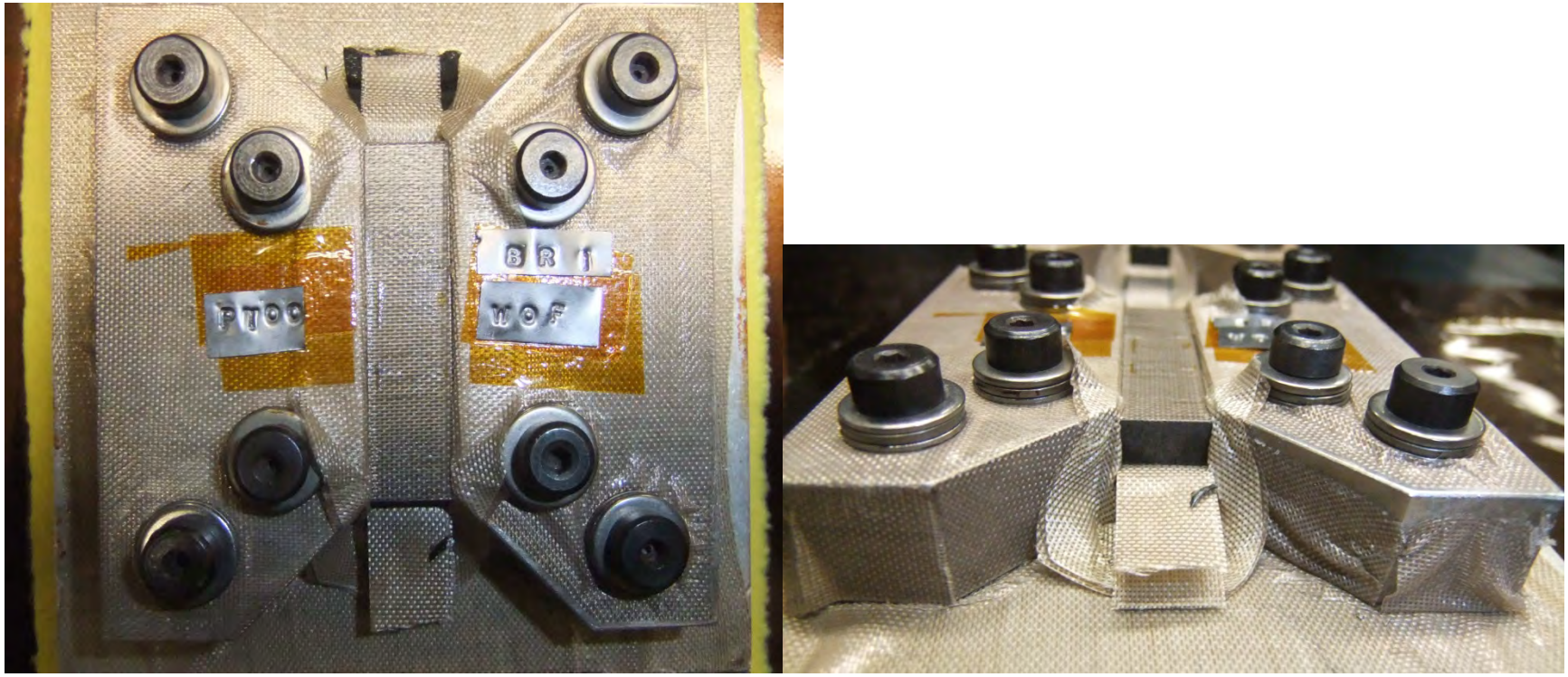
Top View I



Edge - Top Side View

Top View II

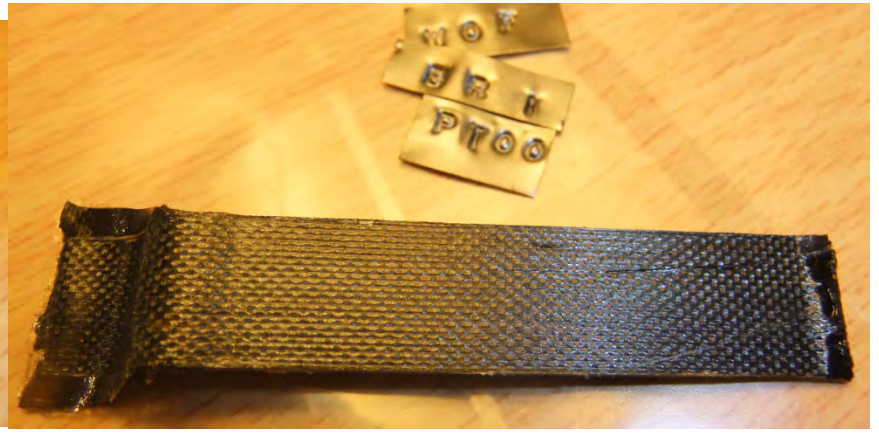
Figure BCF49, Bulk YS80A Composite Specimens made with baseline YS80A fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)



Top View Side View

Figure BCF50, Cured DeBagged Bulk P100S Composite Specimens made with baseline P100S fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

Bottom View I



Top View I

Edge Bottom View

Top View II

Figure BCF51, Bulk P100S Composite Specimens made with baseline P100S fibers/tows **W**ith**O**ut graphite **F**ins (ie WOF)

5.0 APPENDIX C: OPTICAL MICROSCOPY

5.1 Section 1: YSH50 Optical Microscopy

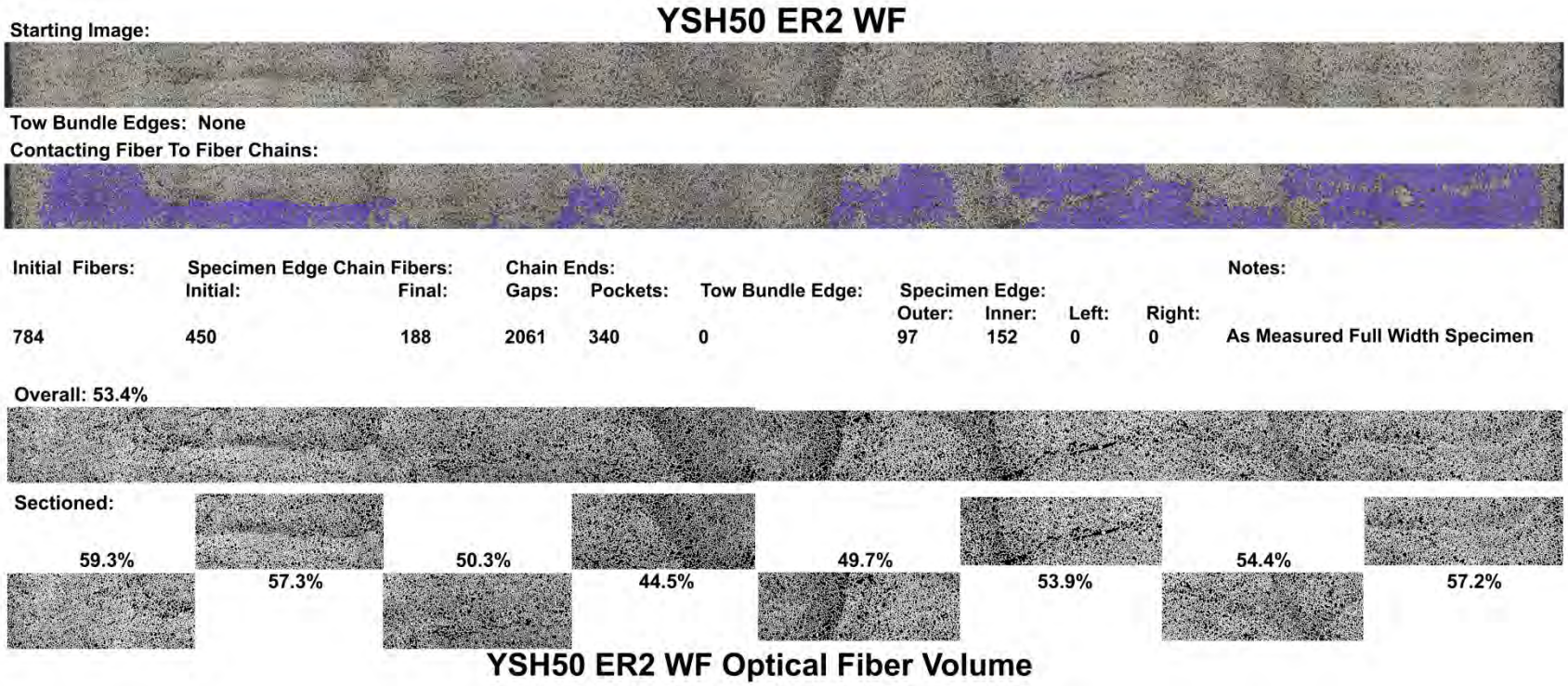


Figure OM1, YSH50A ER2 WF Optical Microscopy, Fiber Volume And Percolation Chains

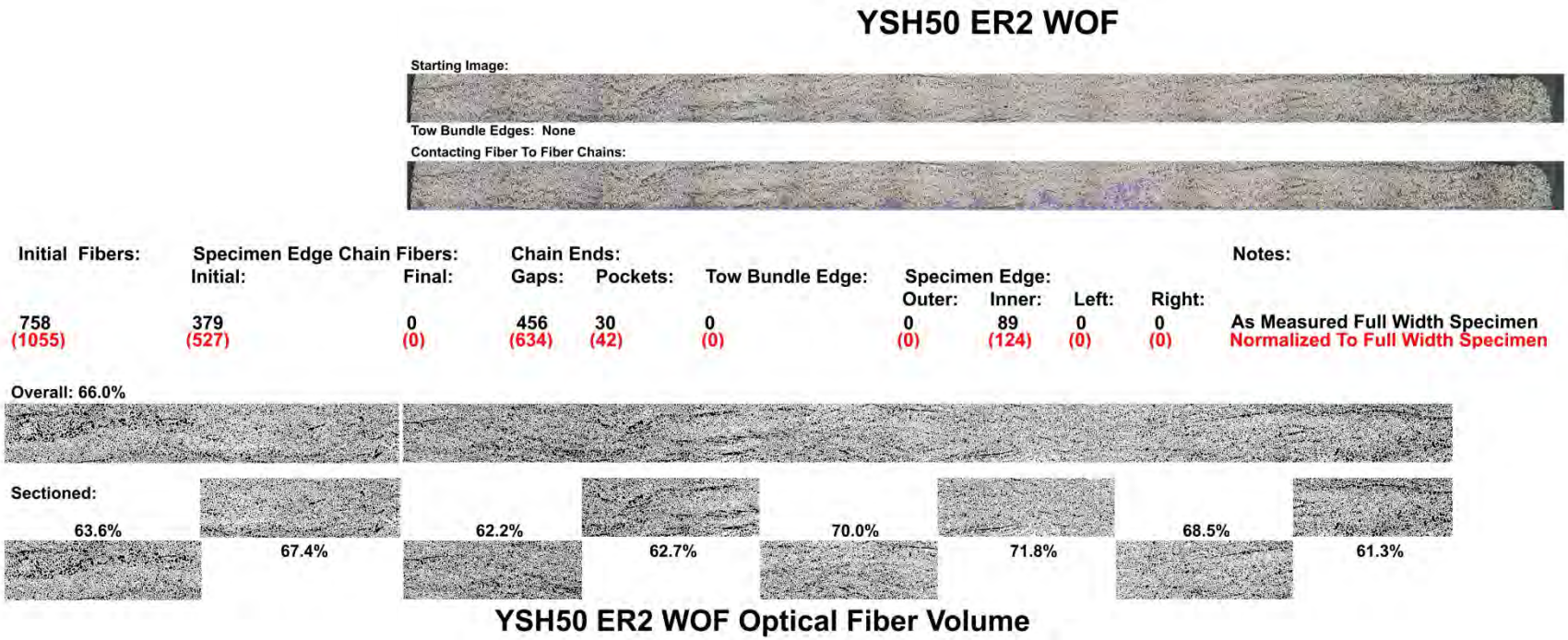


Figure OM2, YSH50A ER2 WOF Optical Microscopy, Fiber Volume And Percolation Chains.

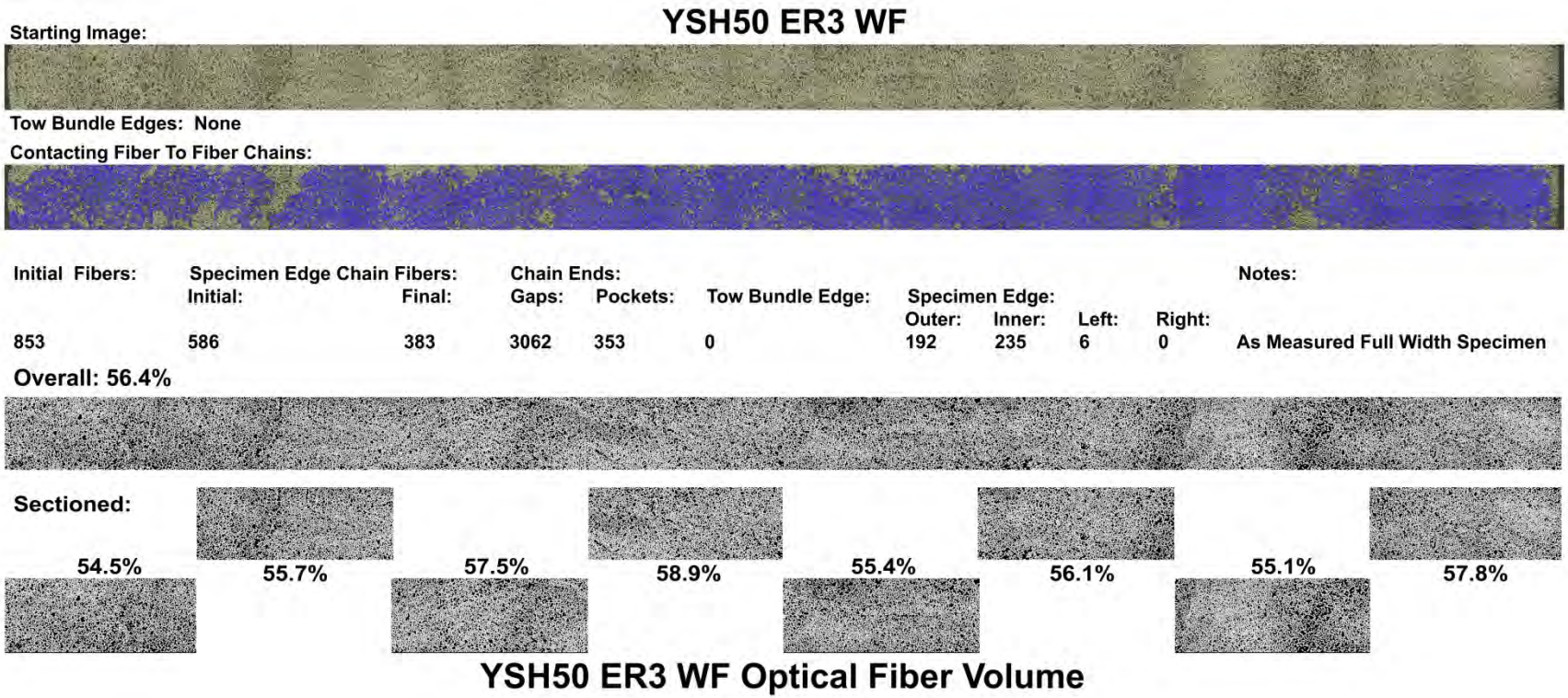


Figure OM3, YSH50A ER3 WF Optical Microscopy, Fiber Volume And Percolation Chains

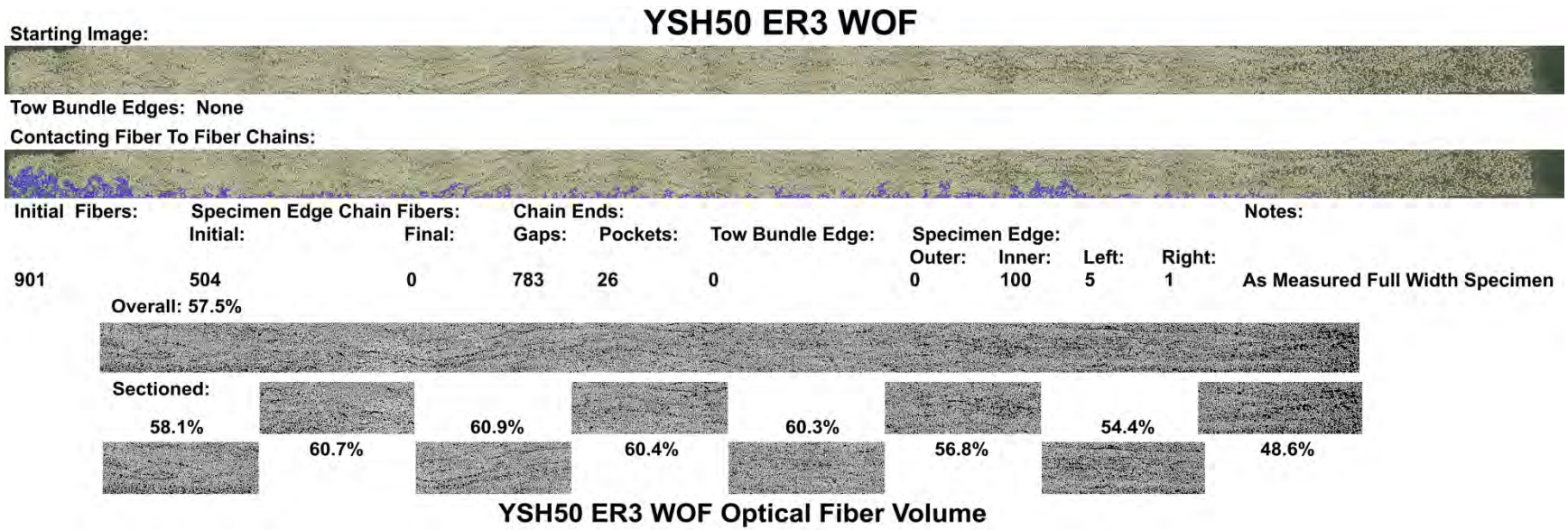


Figure OM4, YSH50A ER3 WOF Optical Microscopy, Fiber Volume And Percolation Chains

5.2 Section 2: YS80A Optical Fiber Volume

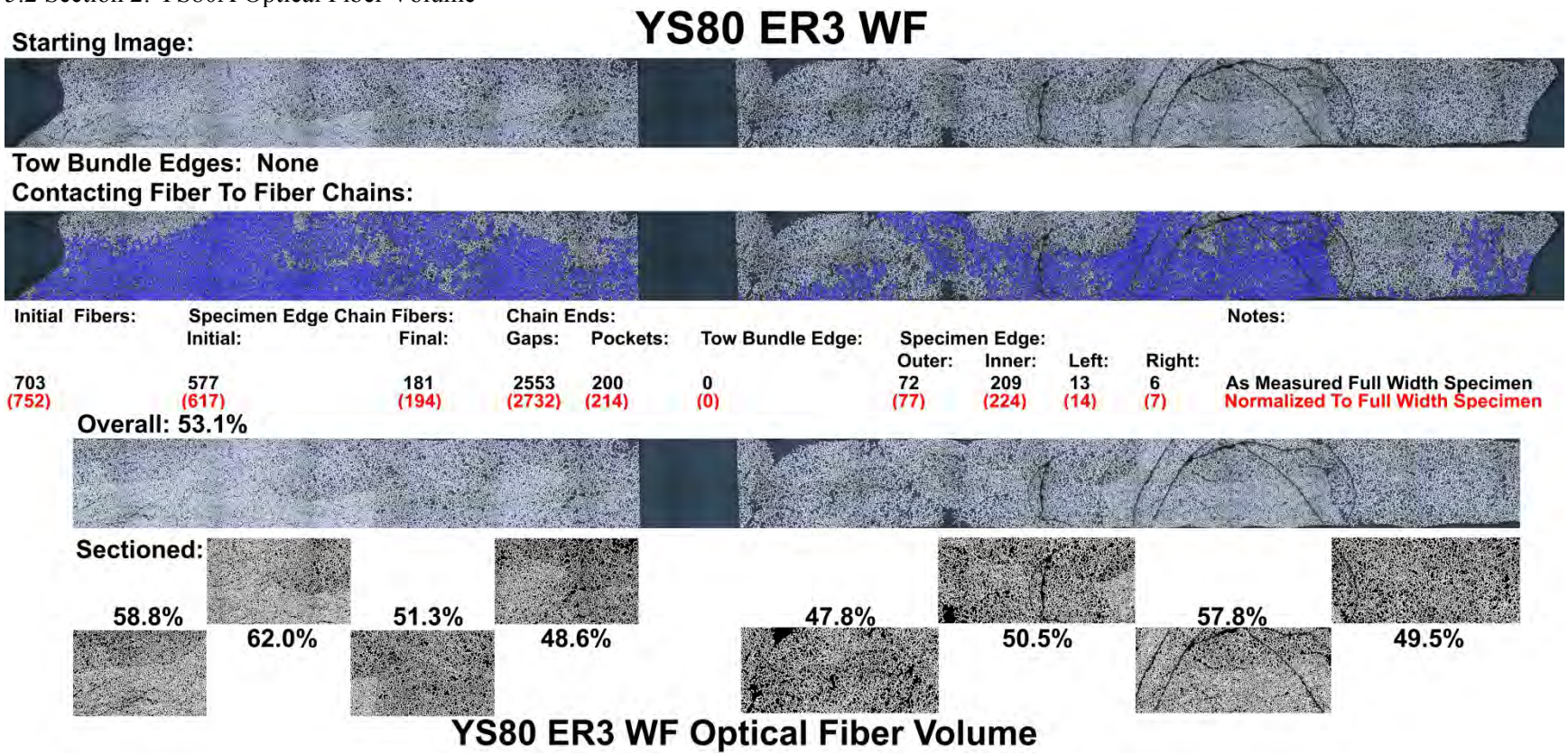


Figure OM5, YS80A ER3 WF Optical Microscopy, Fiber Volume And Percolation Chains

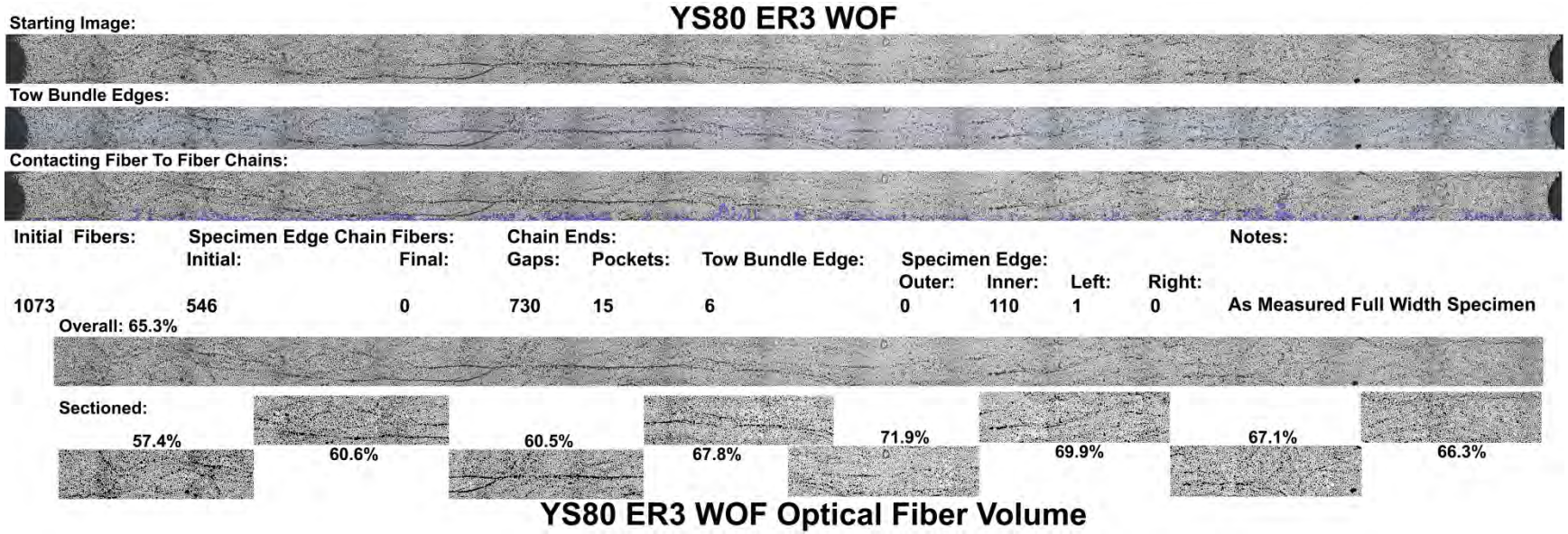


Figure OM6, YS80A ER3 WOF Optical Microscopy, Fiber Volume And Percolation Chains

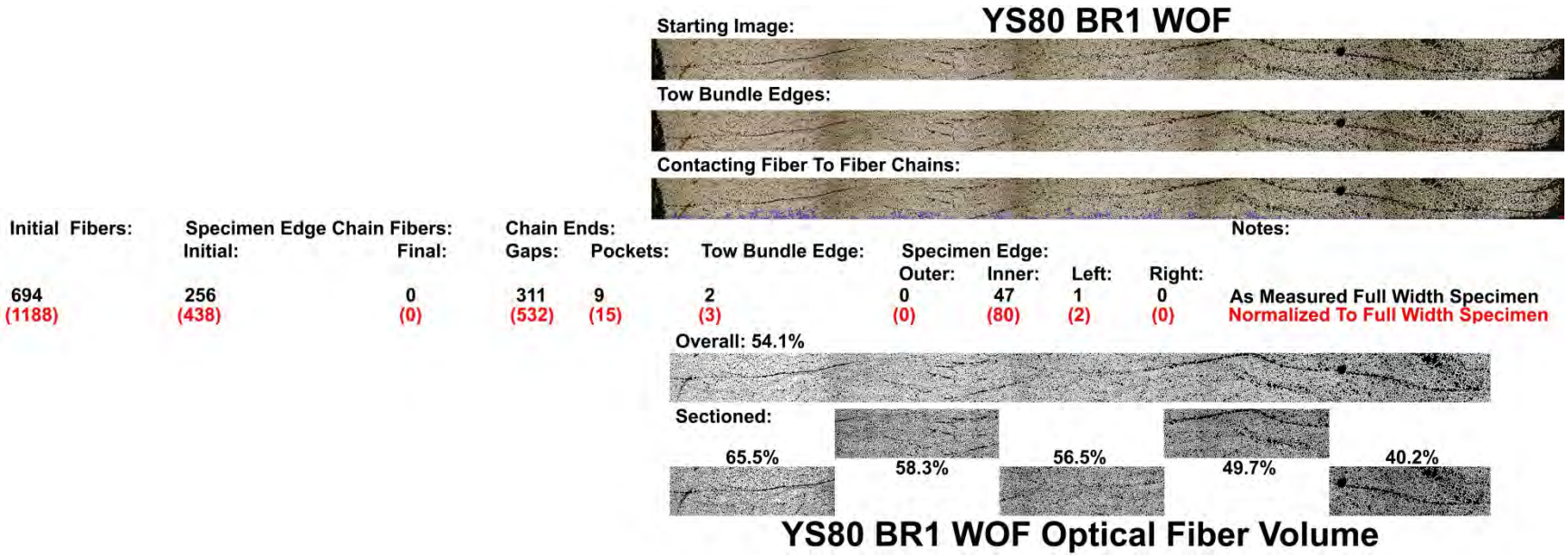


Figure OM7, YS80A BR1 WOF Optical Microscopy, Fiber Volume And Percolation Chains

5.3 Section 3: P100S Optical Microscopy

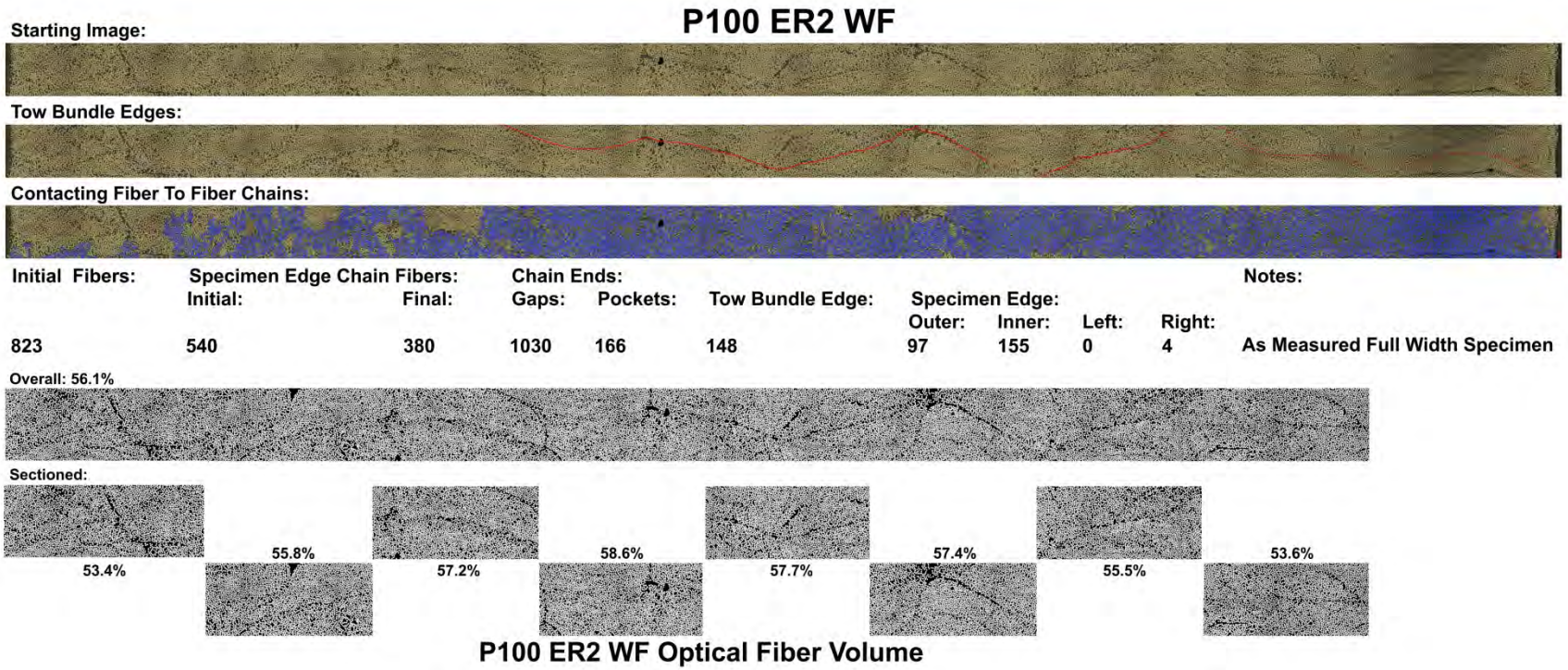


Figure OM8, P100S ER2 WF Optical Microscopy, Fiber Volume And Percolation Chains

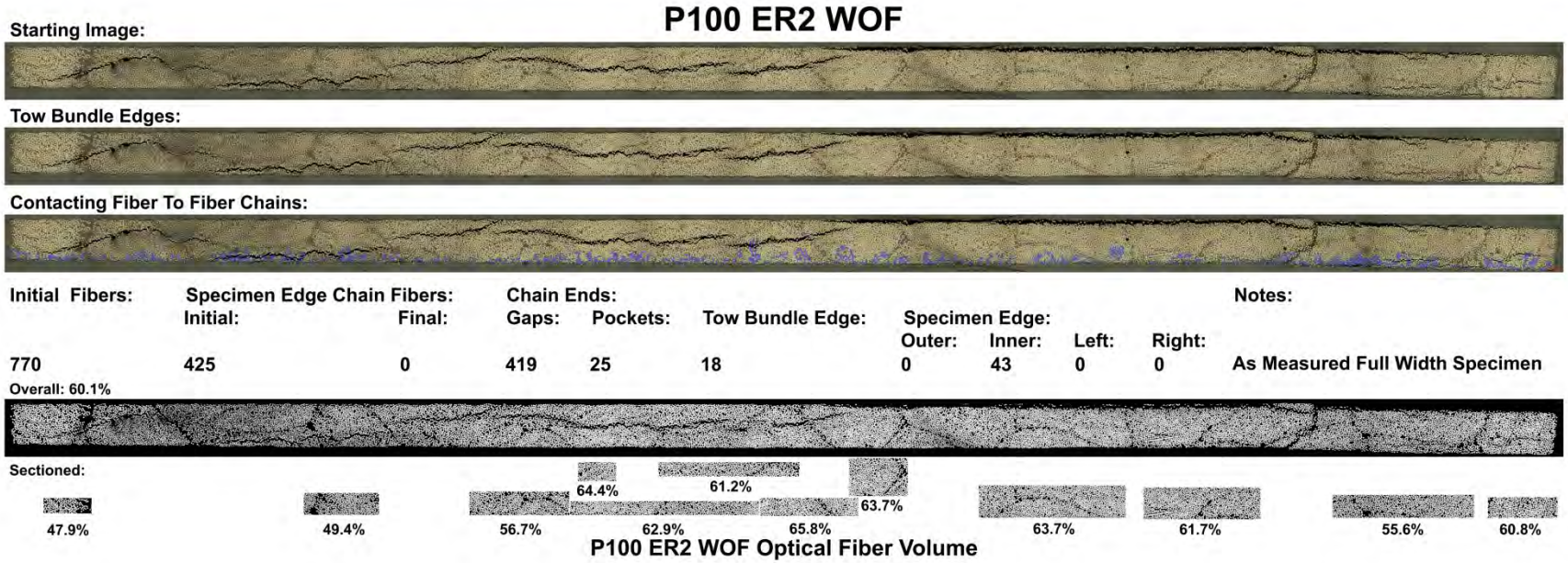


Figure OM9, P100S ER2 WOF Optical Microscopy, Fiber Volume And Percolation Chains

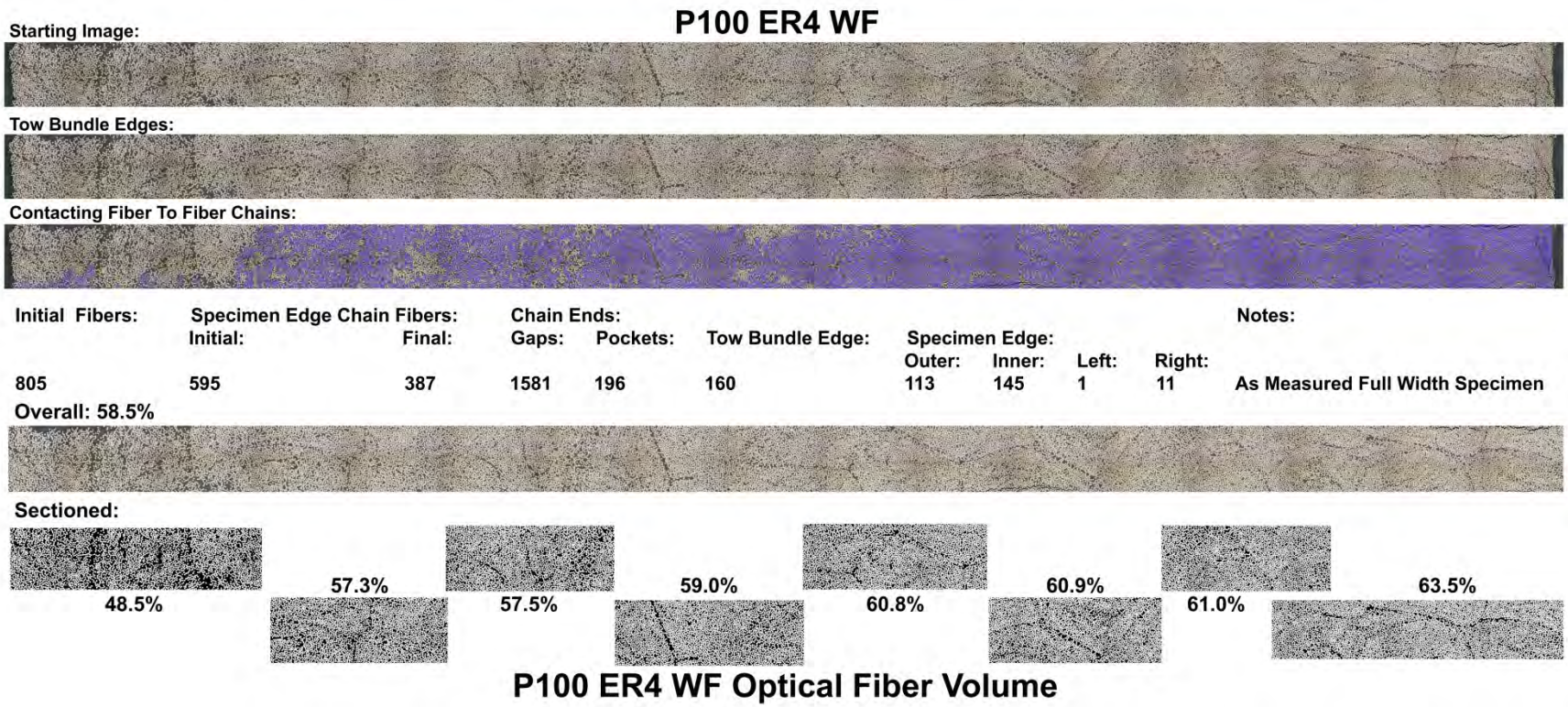


Figure OM10, P100S ER4 WF Optical Microscopy, Fiber Volume And Percolation Chains

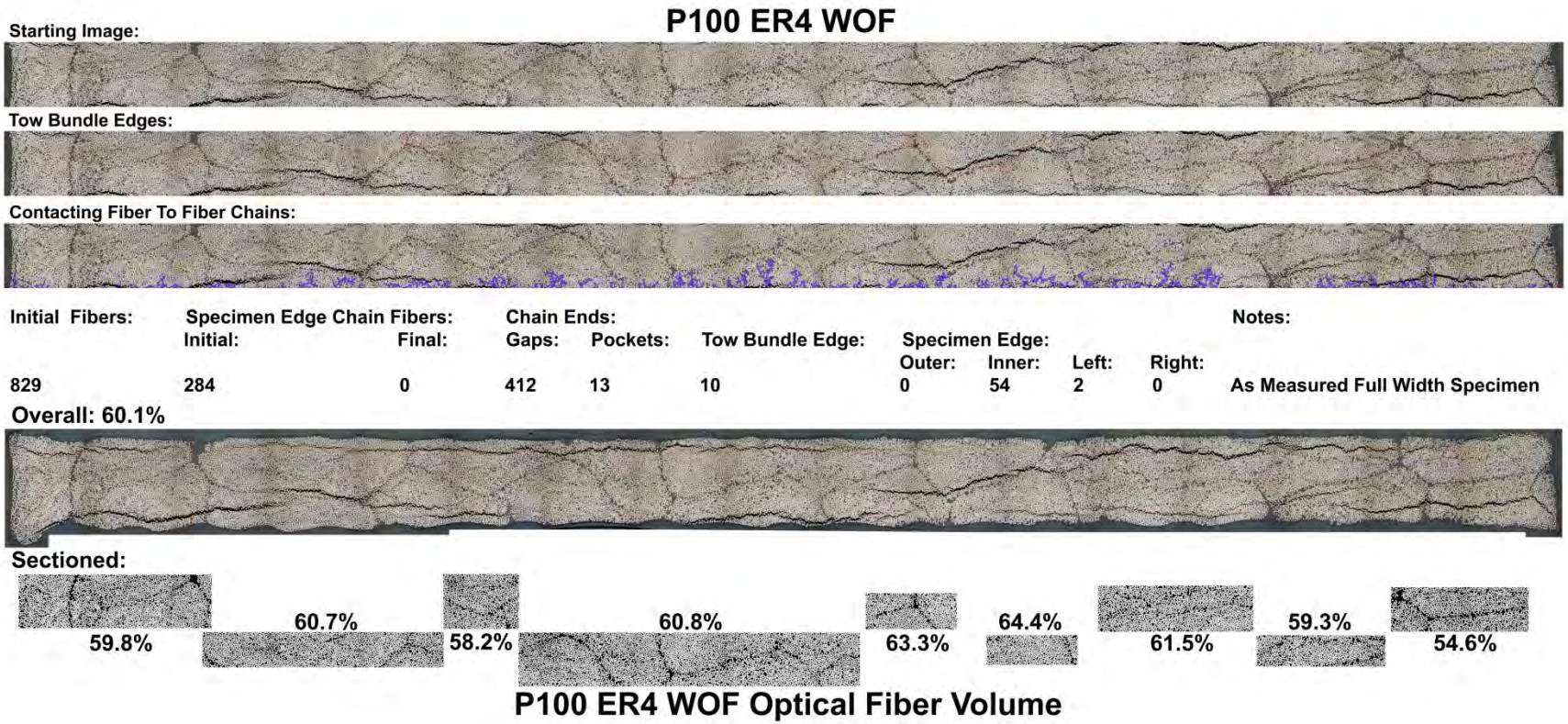


Figure OM11, P100S ER4 WOF Optical Microscopy, Fiber Volume And Percolation Chains

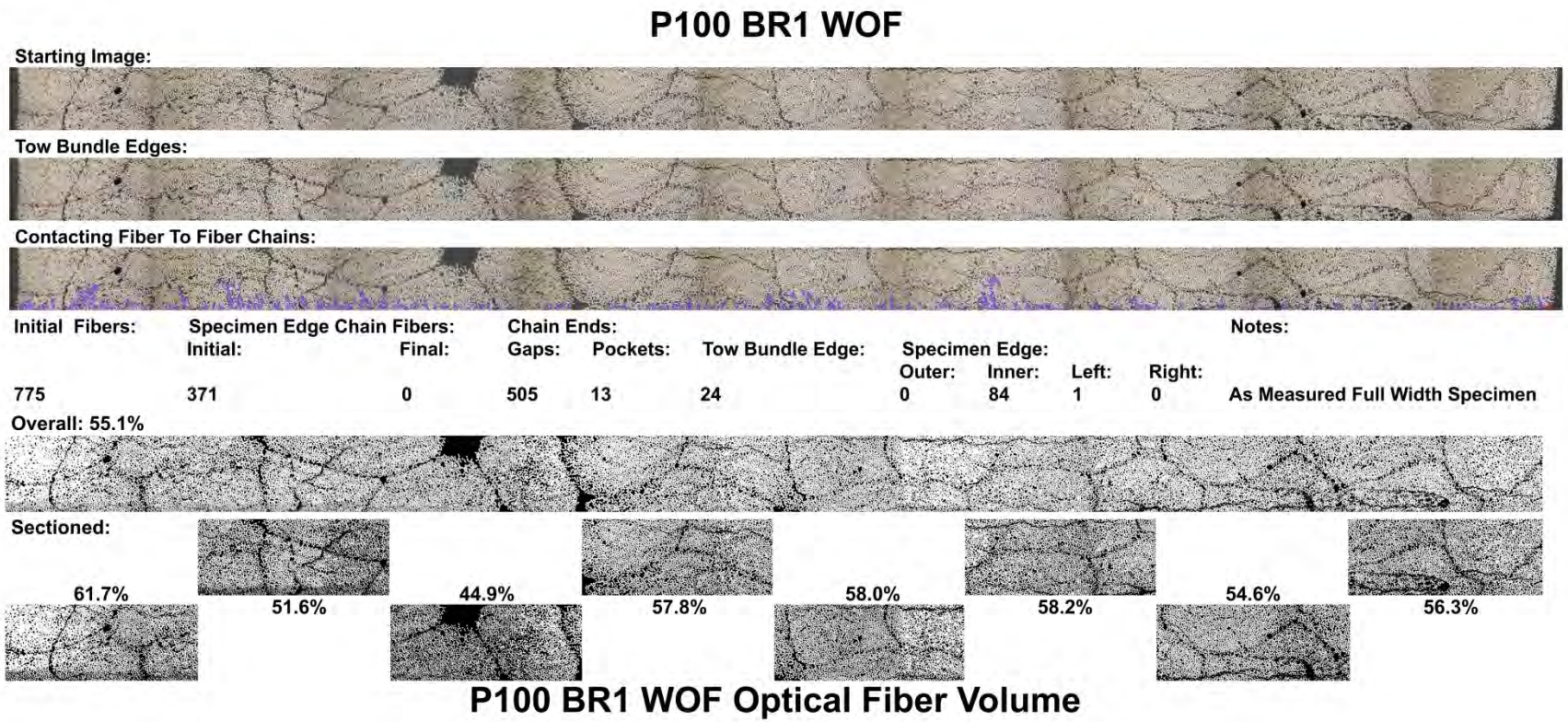


Figure OM12, P100S BR1 WOF Optical Microscopy, Fiber Volume And Percolation Chains

6.0 APPENDIX D: HEAT CAPACITY

6.1 Section 1: YSH50A Composites

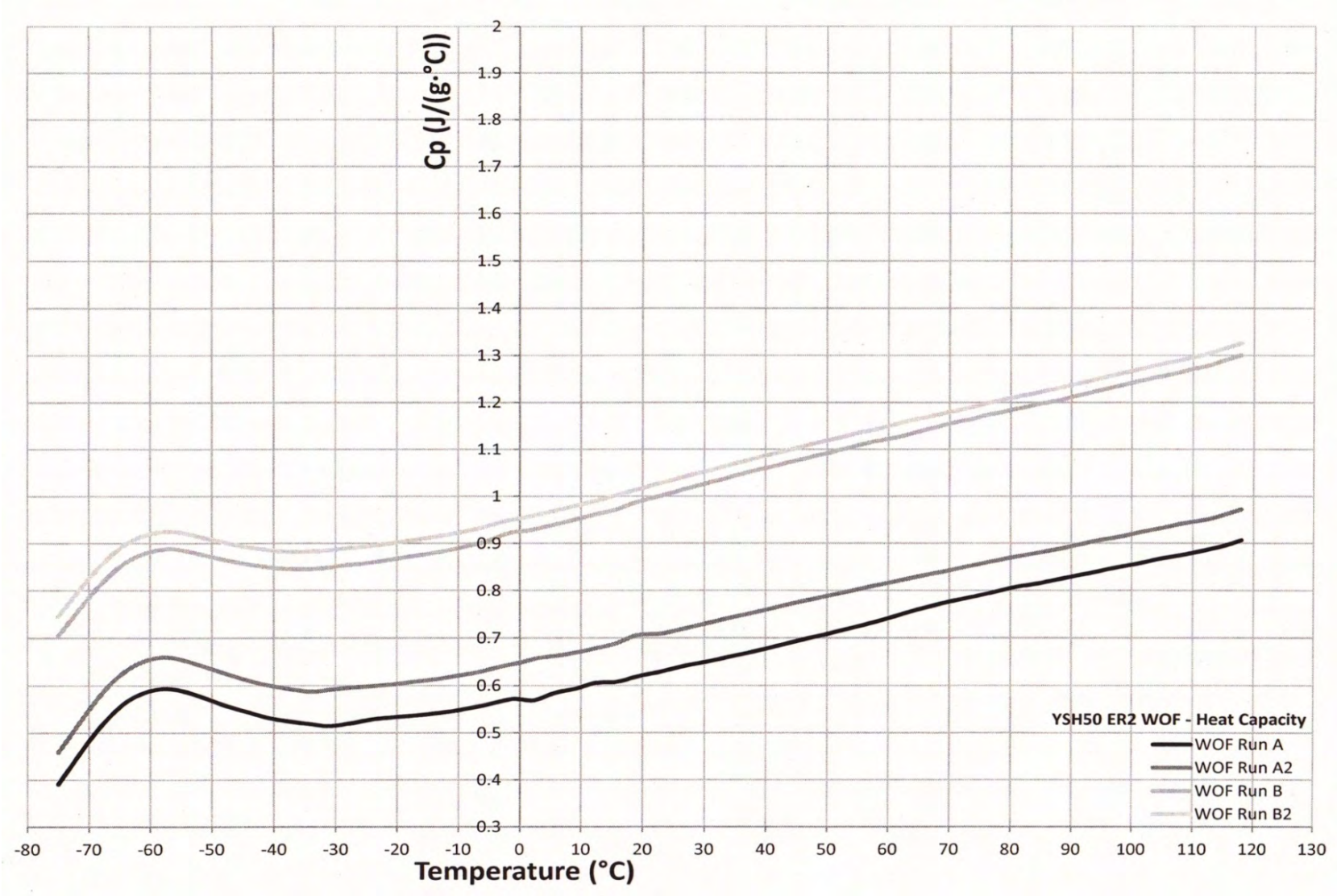


Figure HC1, Heat Capacity Curves for YSH50A ER2 WOF

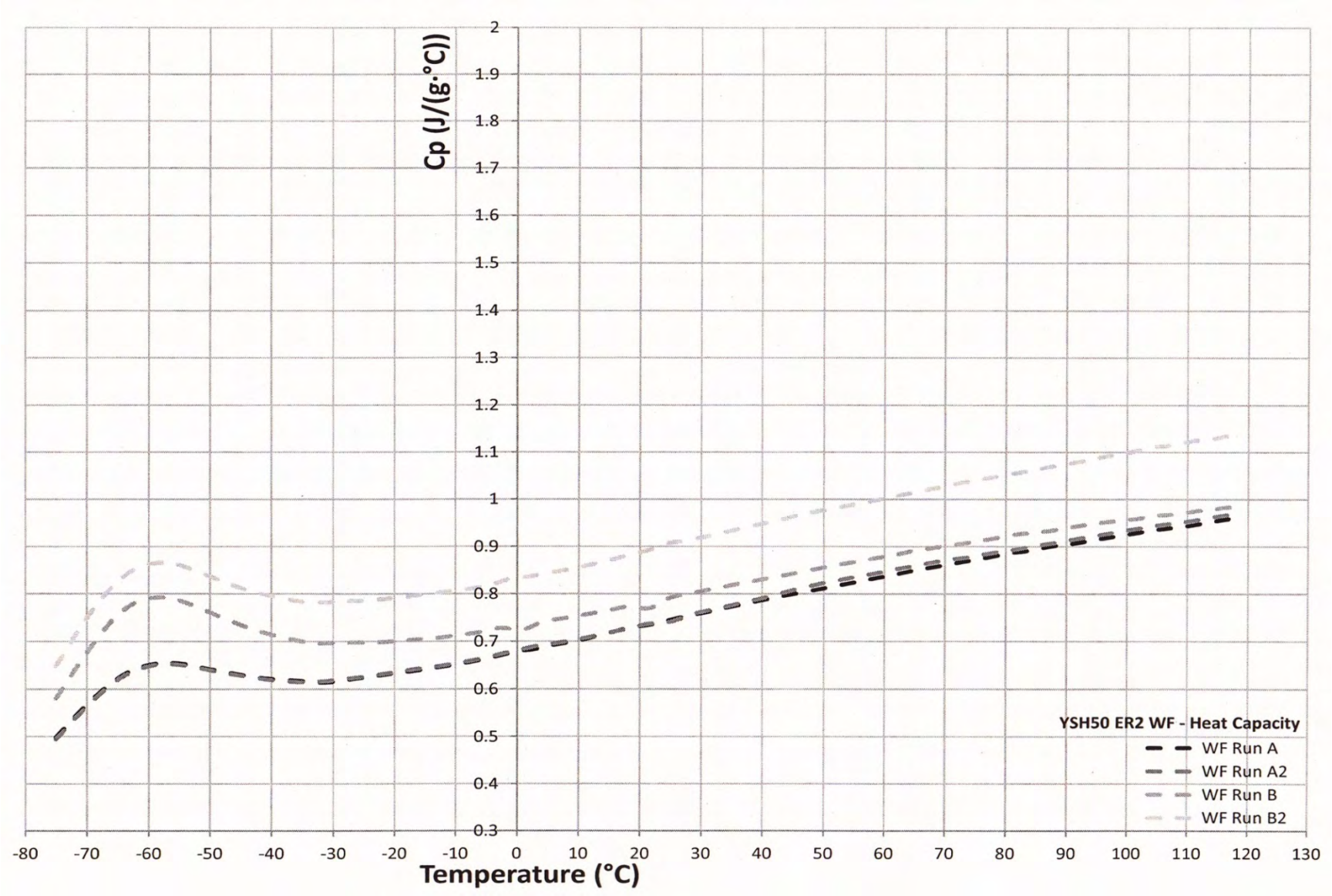


Figure HC2, Heat Capacity Curves for YSH50A ER2 WF

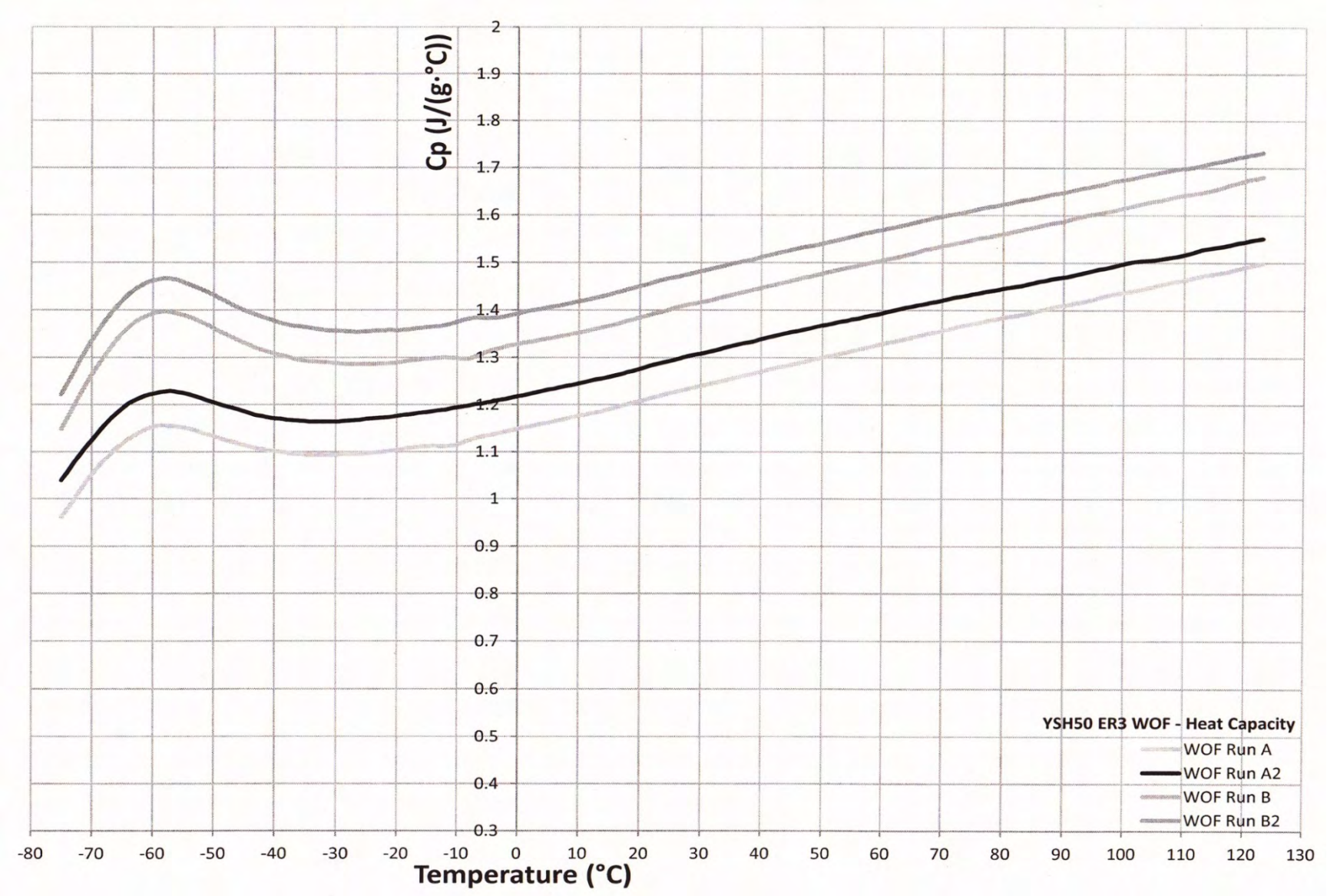


Figure HC3, Heat Capacity Curves for YSH50A ER3 WOF

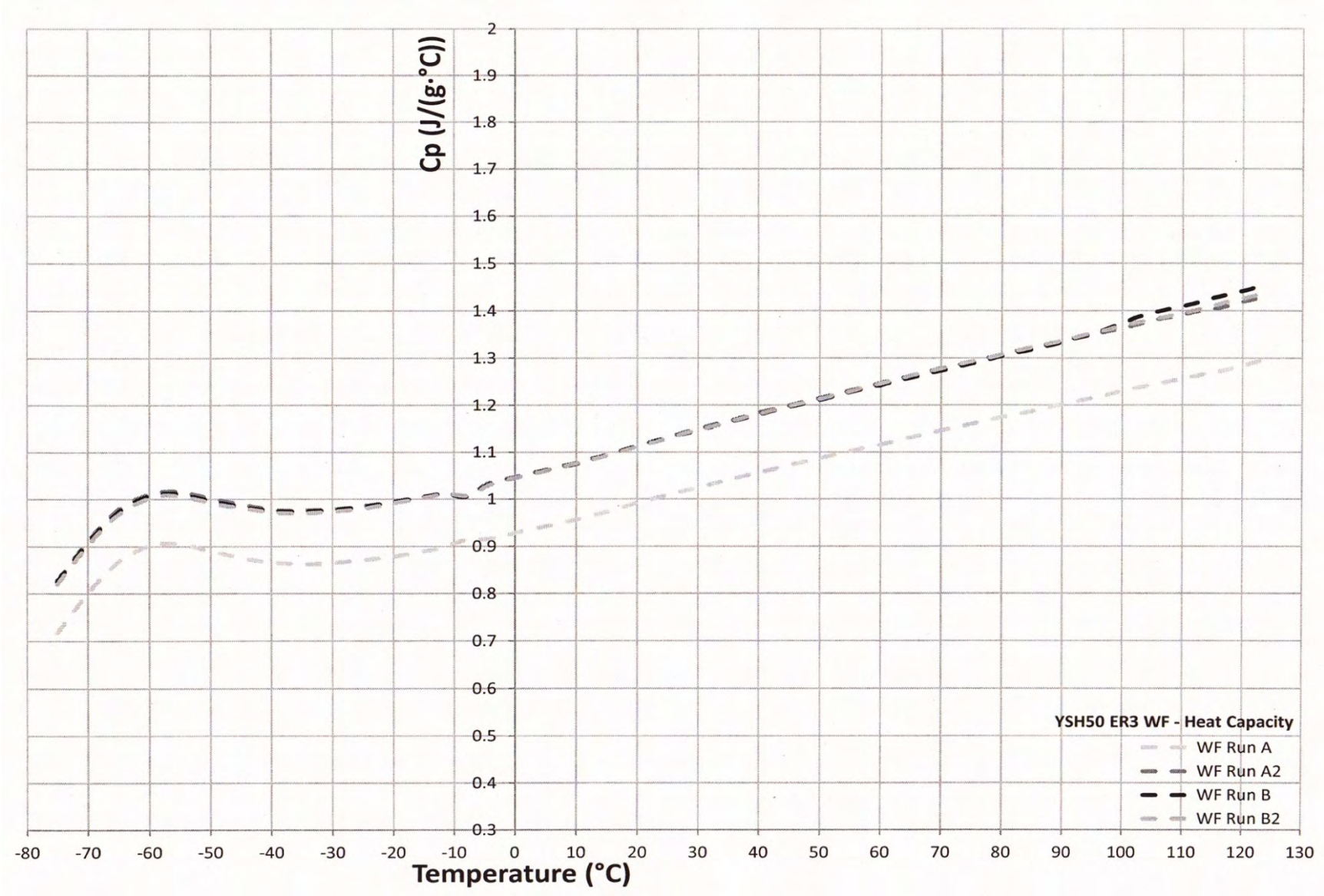


Figure HC4, Heat Capacity Curves for YSH50A ER3 WF

5.2 Section 2: YS80A Composites

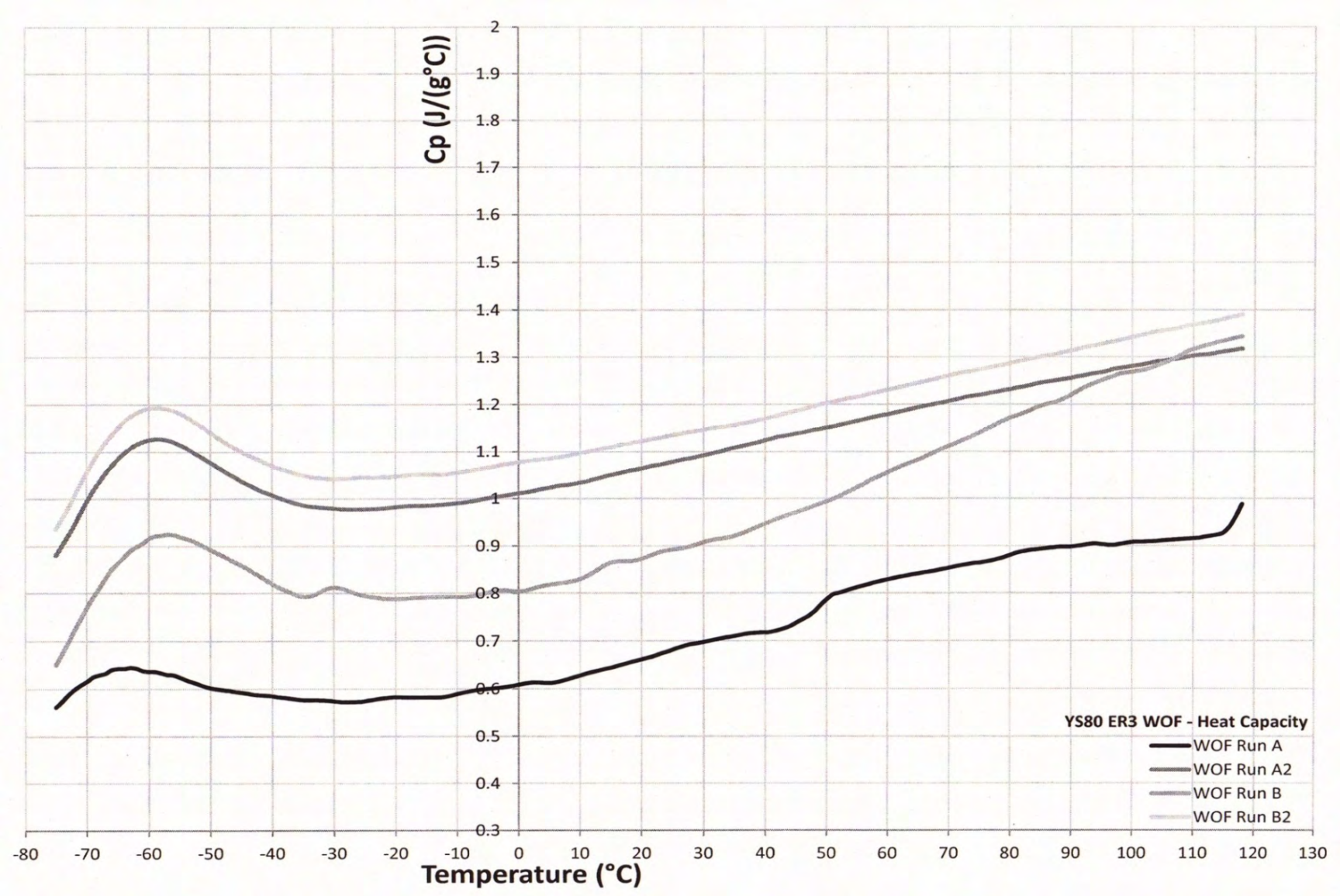


Figure HC5, Heat Capacity Curves for YS80A ER3 Initial WOF

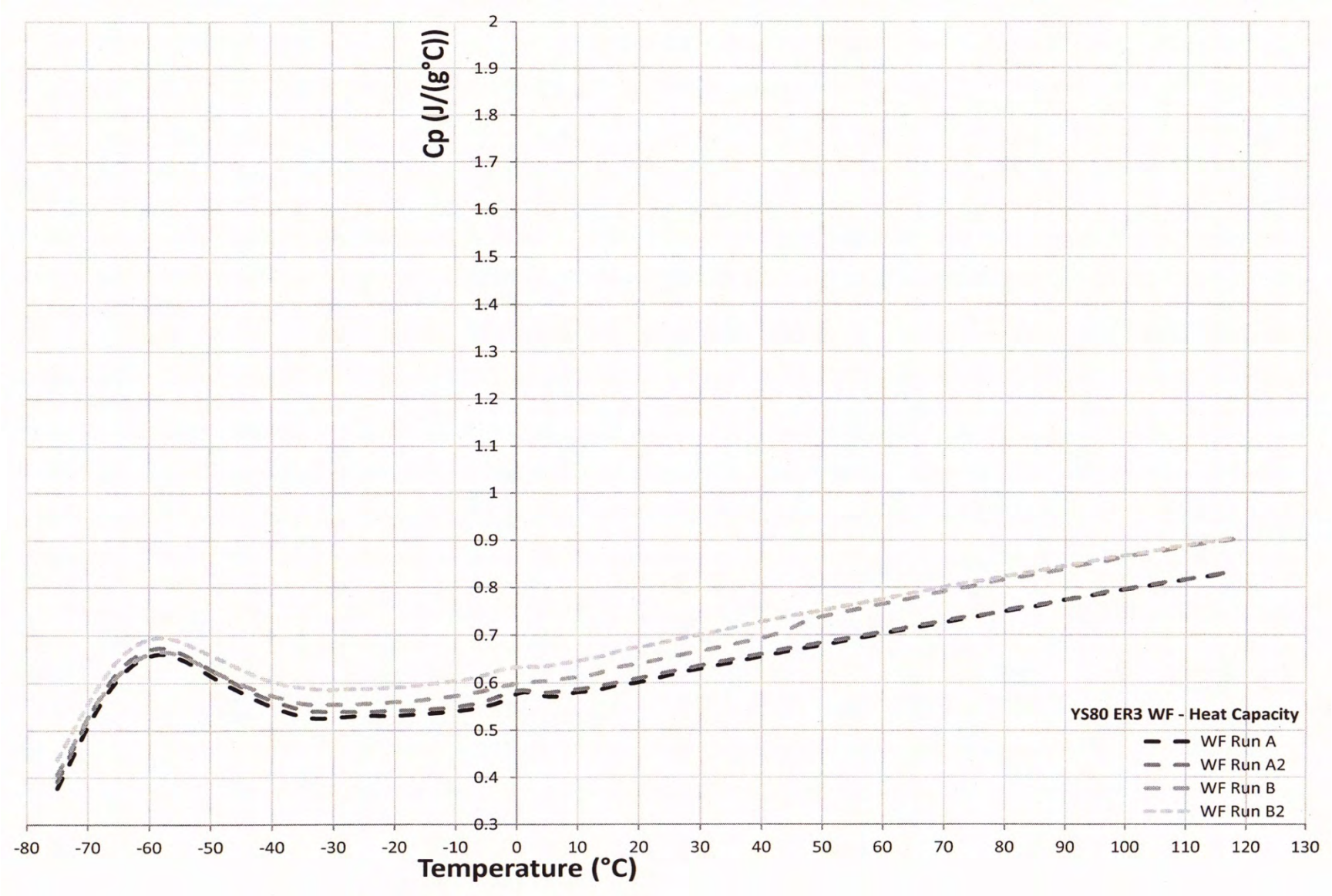


Figure HC6, Heat Capacity Curves for YS80A ER3 Initial WF

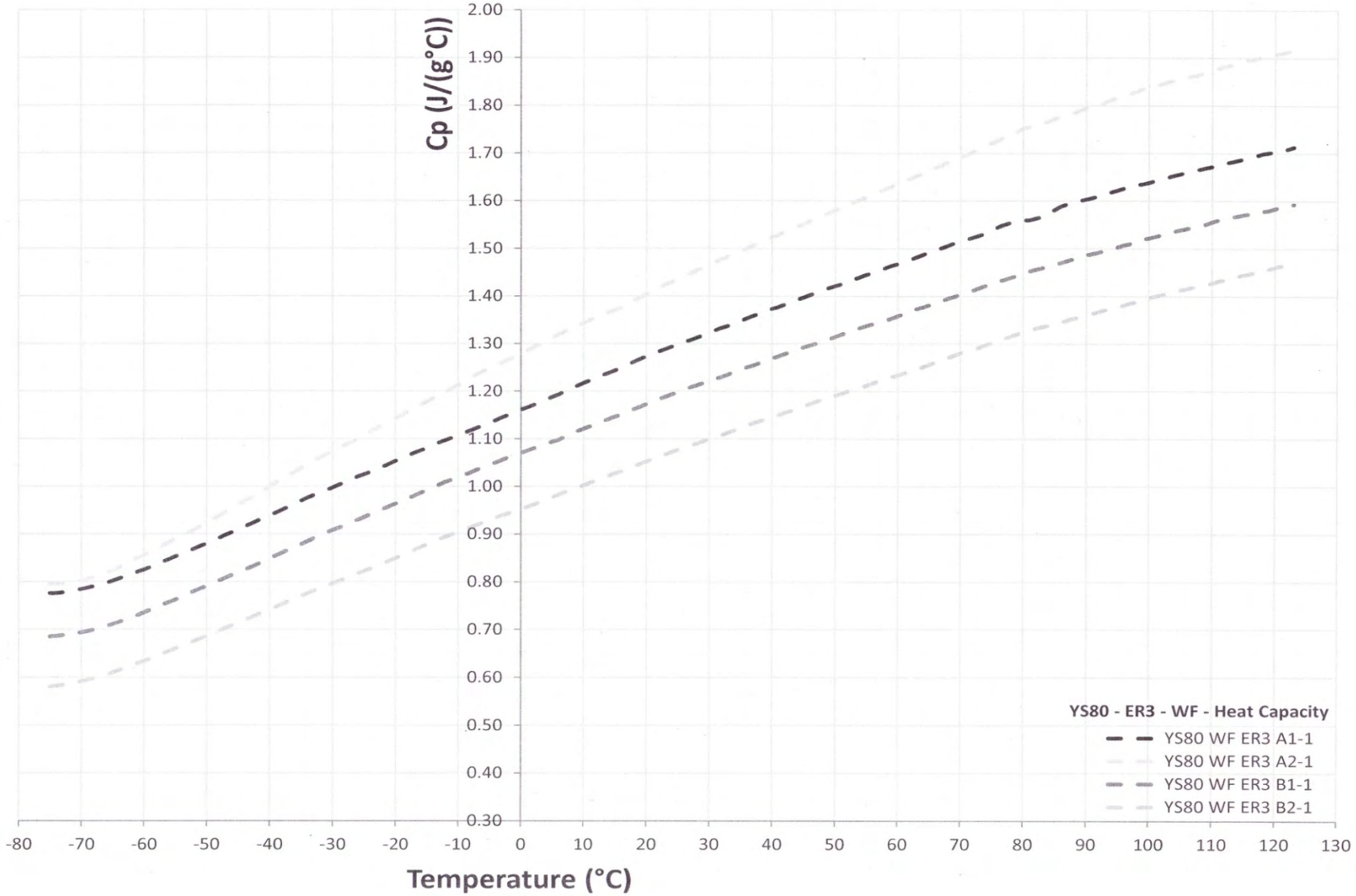


Figure HC7, Heat Capacity Curves for YS80A ER3 Rerun WF

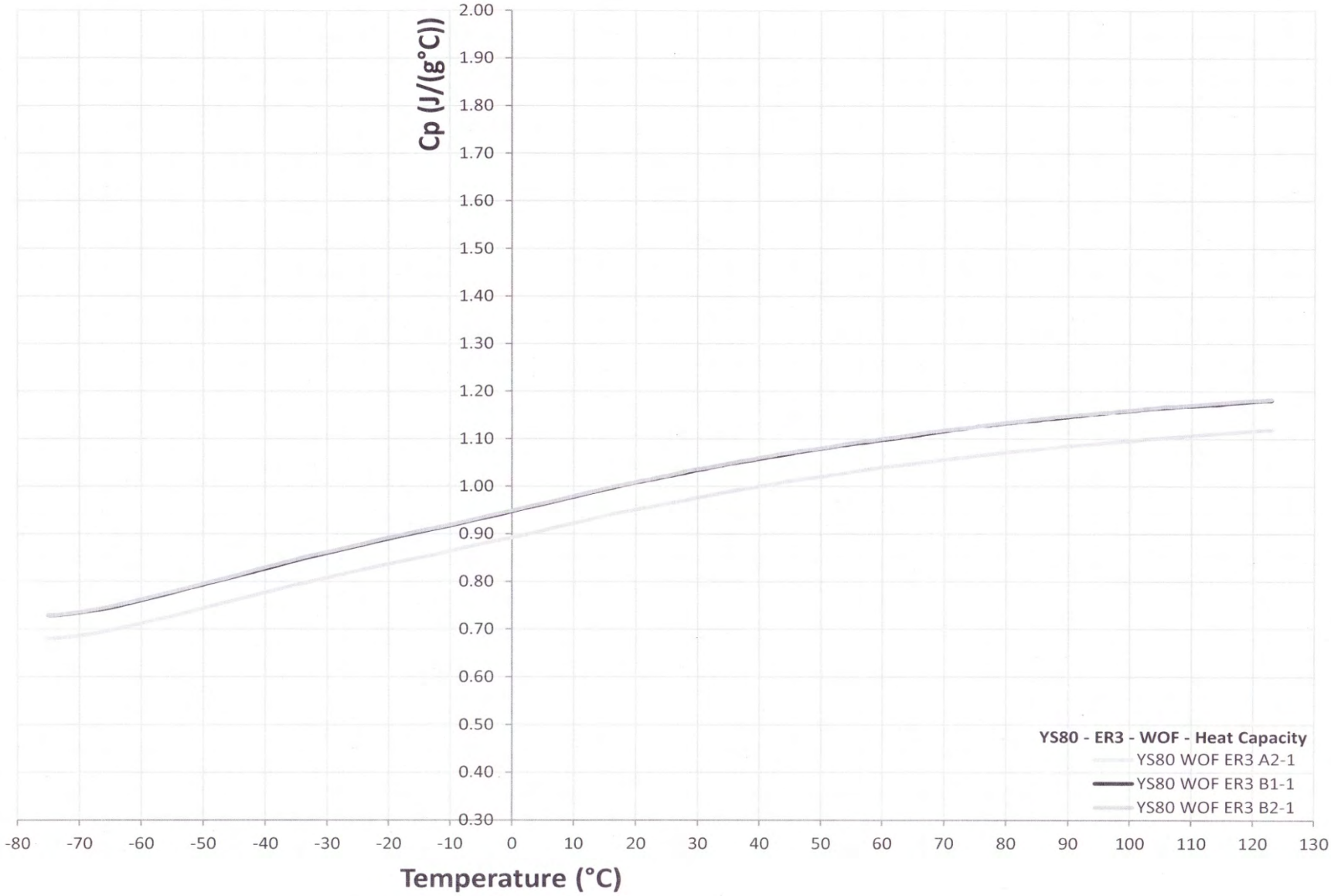


Figure HC8, Heat Capacity Curves for YS80A ER3 Rerun WOF

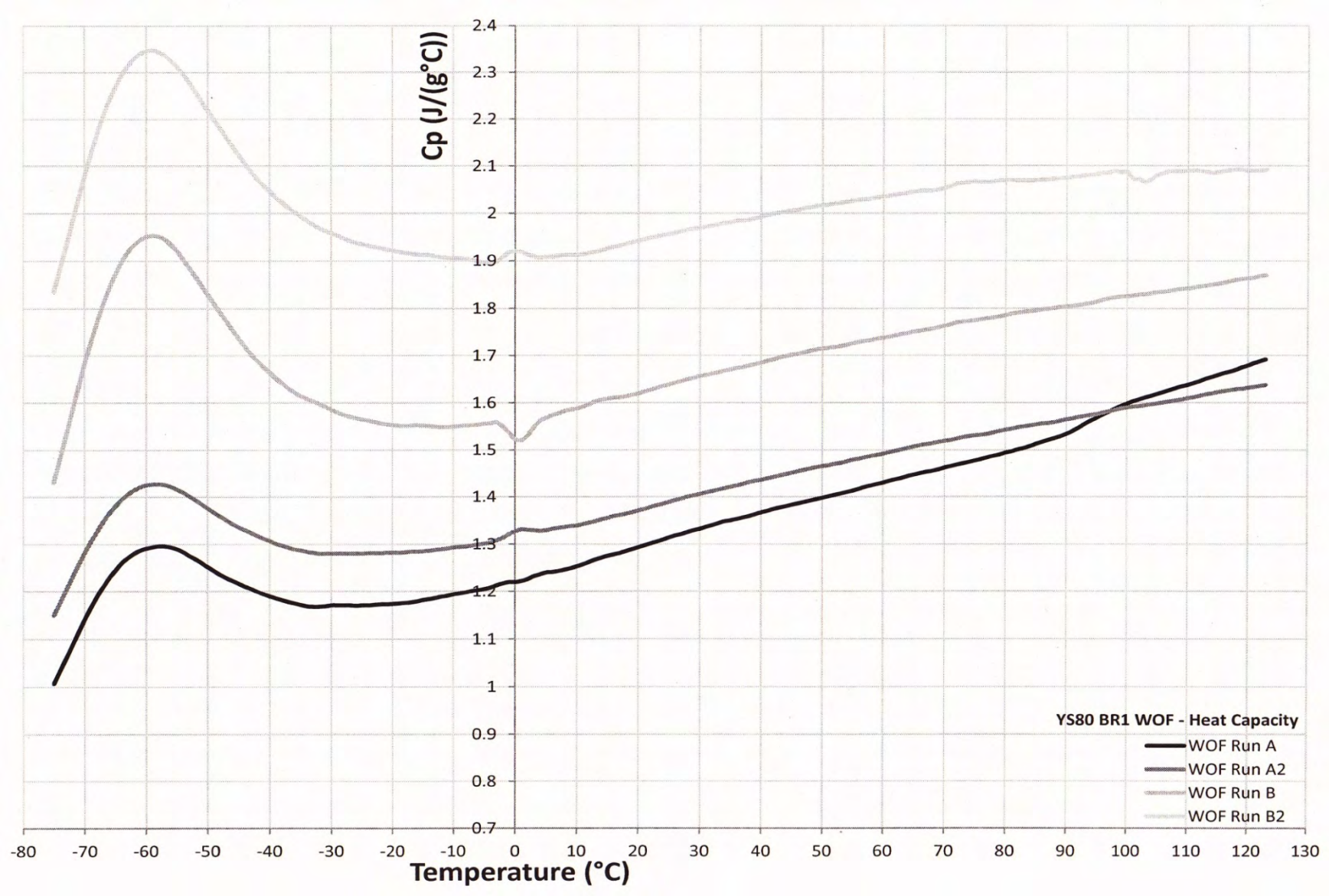


Figure HC9, Heat Capacity Curves for YS80A BR1 Initial WOF

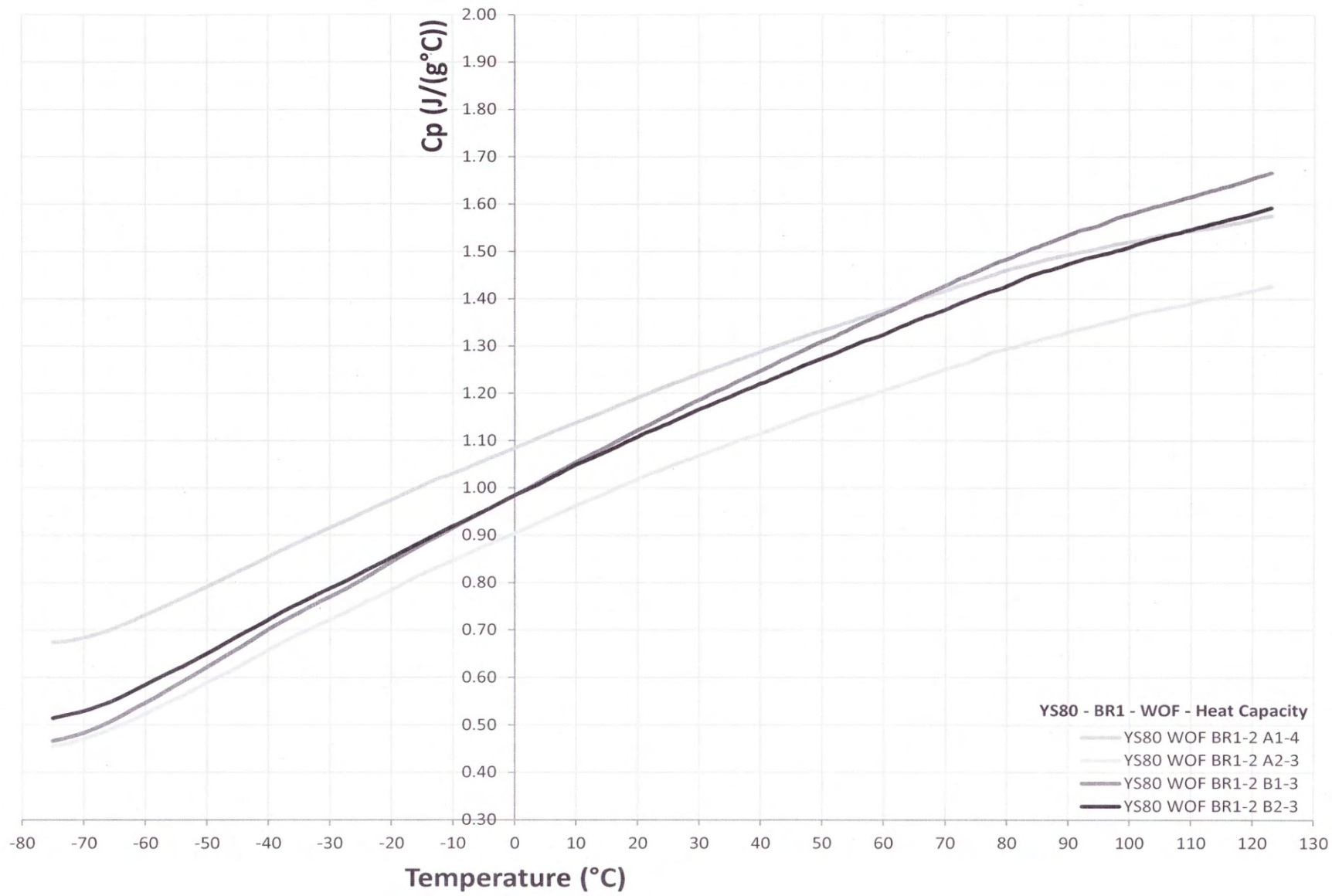


Figure HC10, Heat Capacity Curves for YS80A BR1 Rerun WOF

6.3 Section 3: P100S Composites

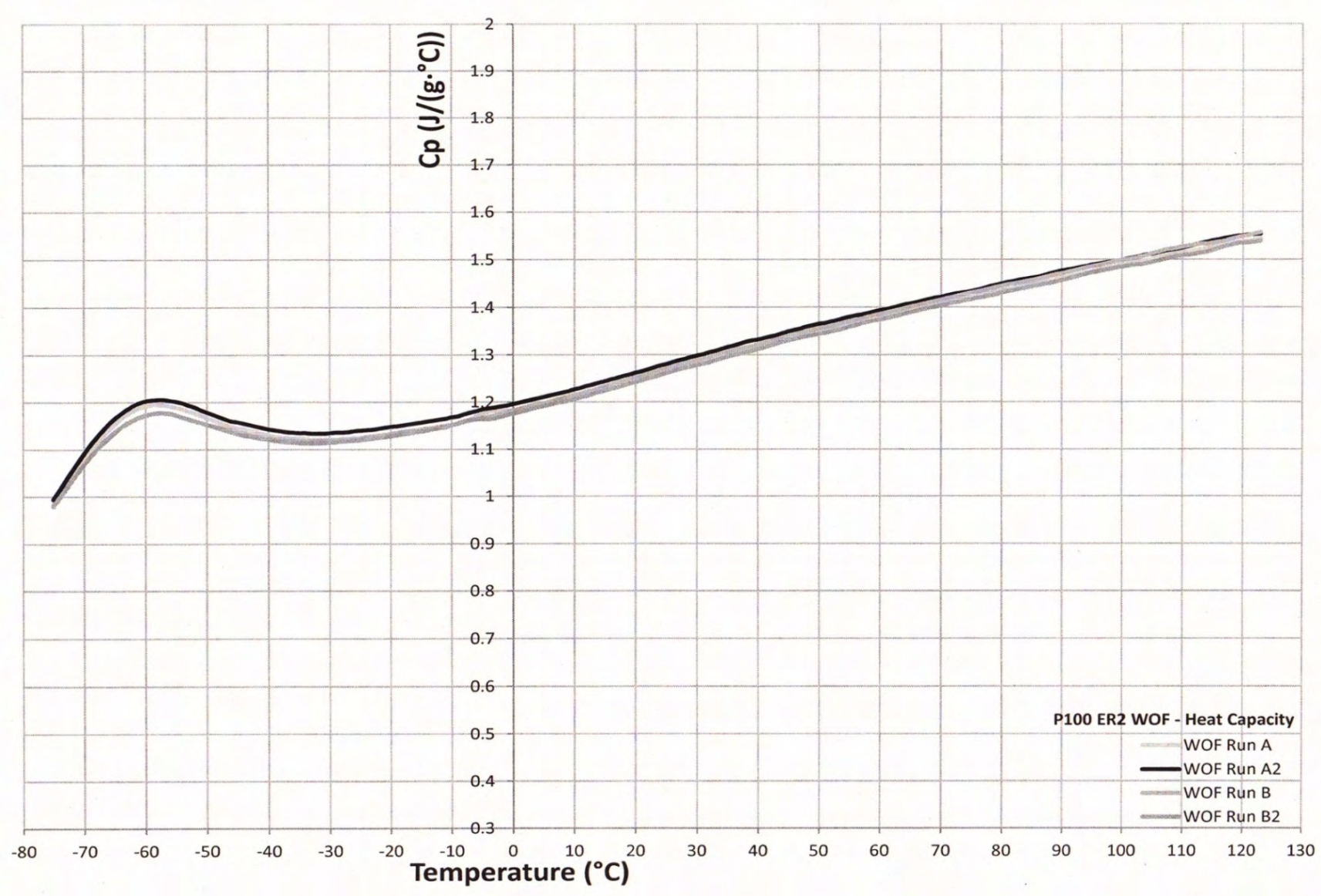


Figure HC11, Heat Capacity Curves for P100S ER2 WOF

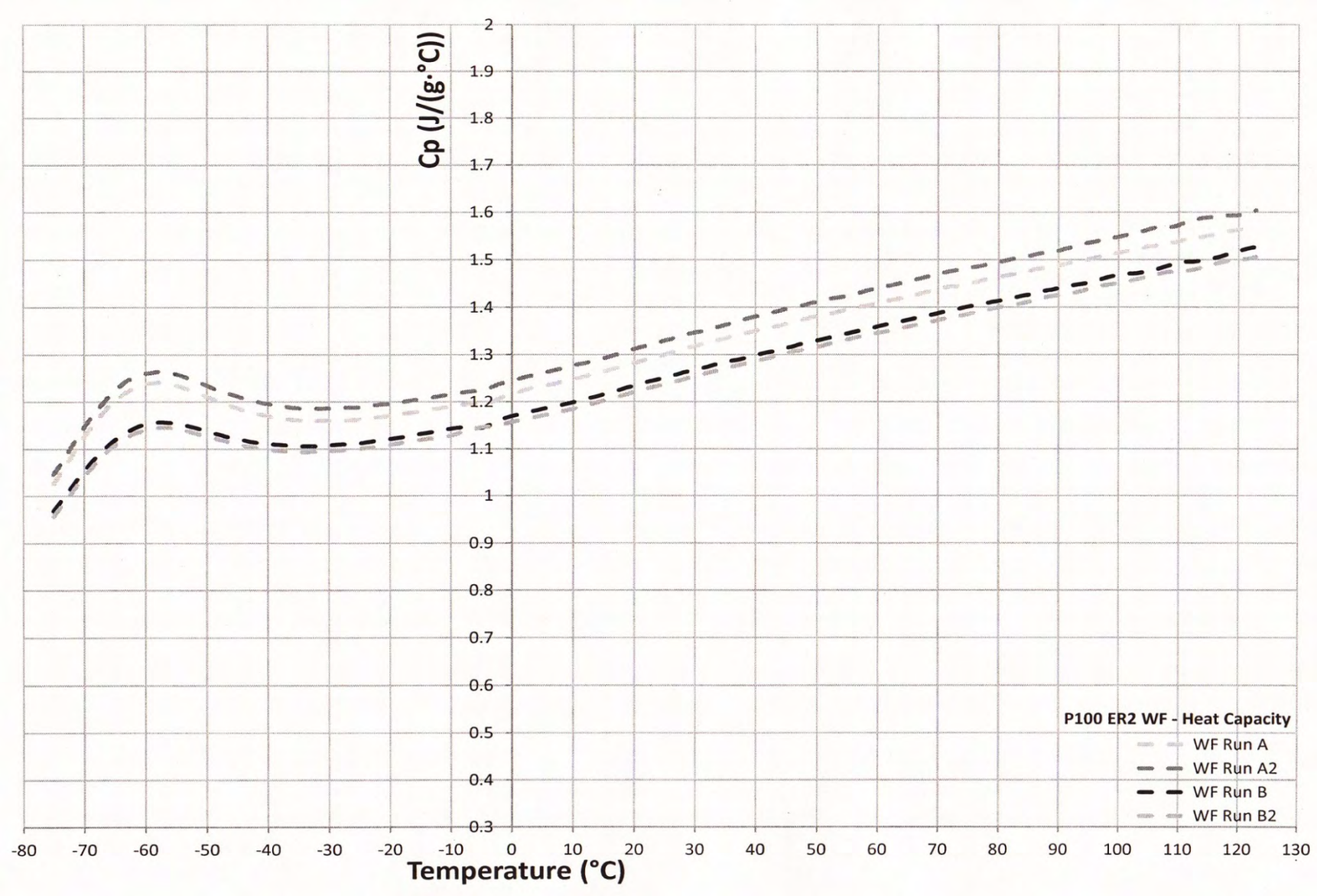


Figure HC12, Heat Capacity Curves for P100S ER2 WF

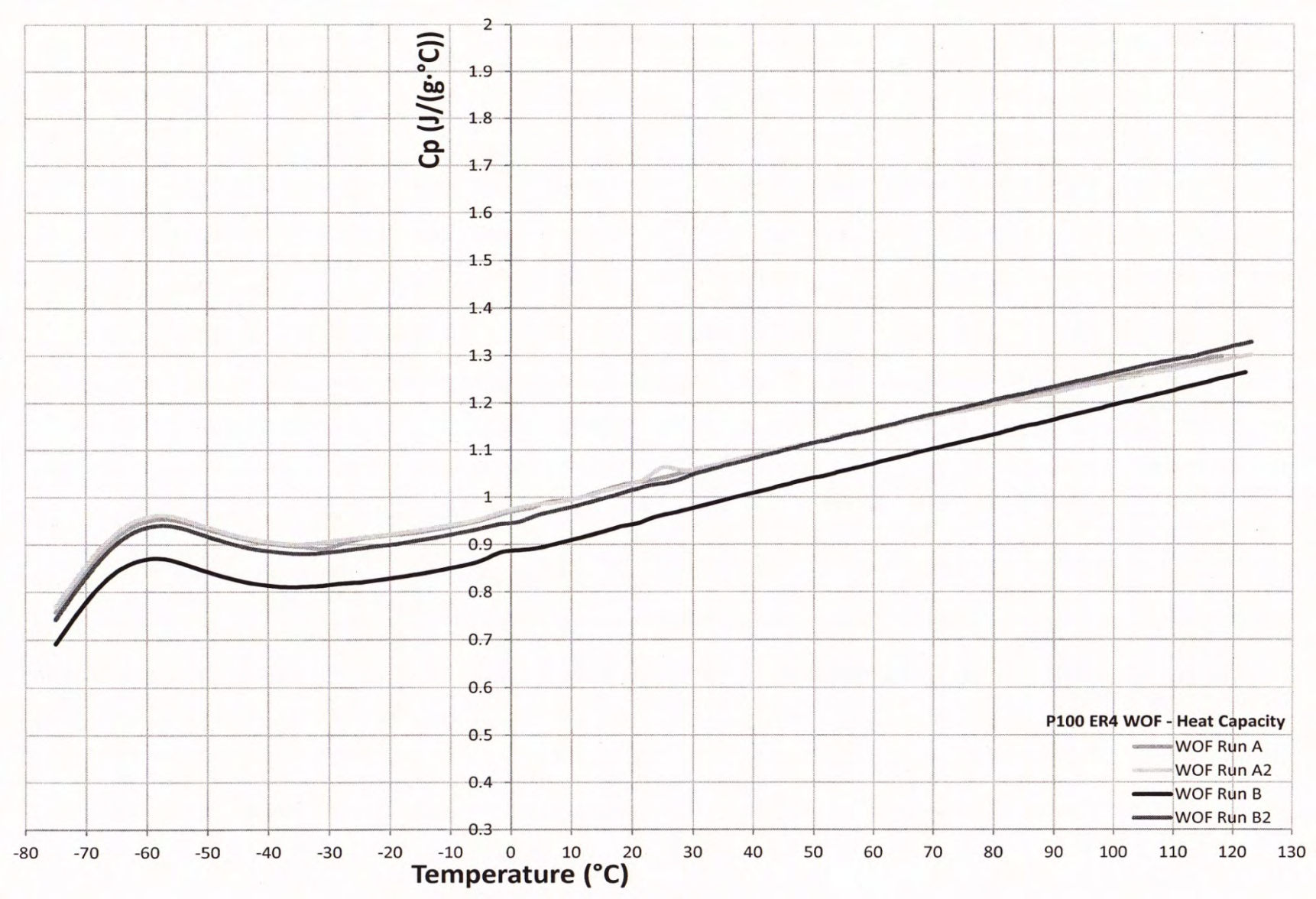


Figure HC13, Heat Capacity Curves for P100S ER4 WOF

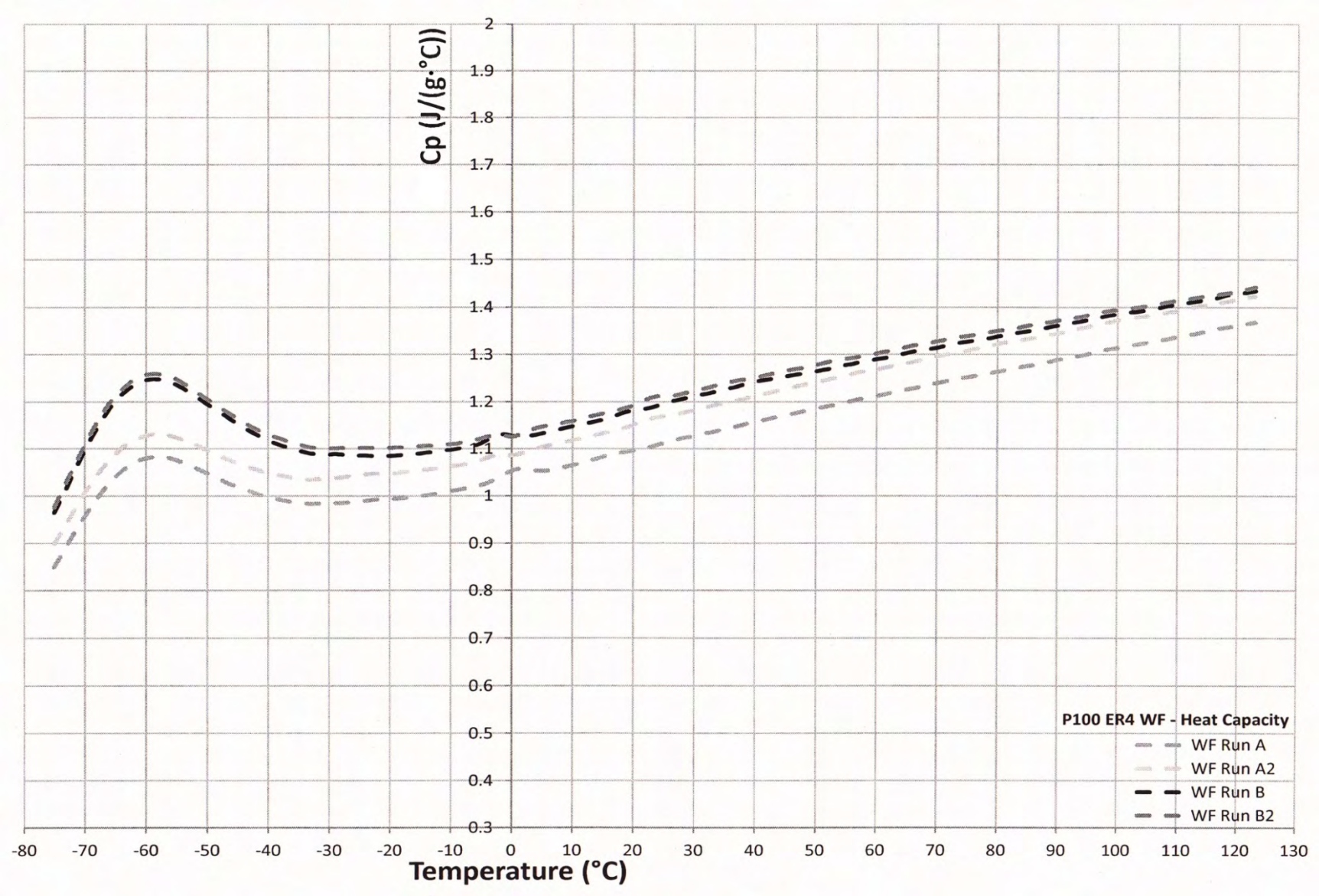


Figure HC14, Heat Capacity Curves for P100S ER4 WF

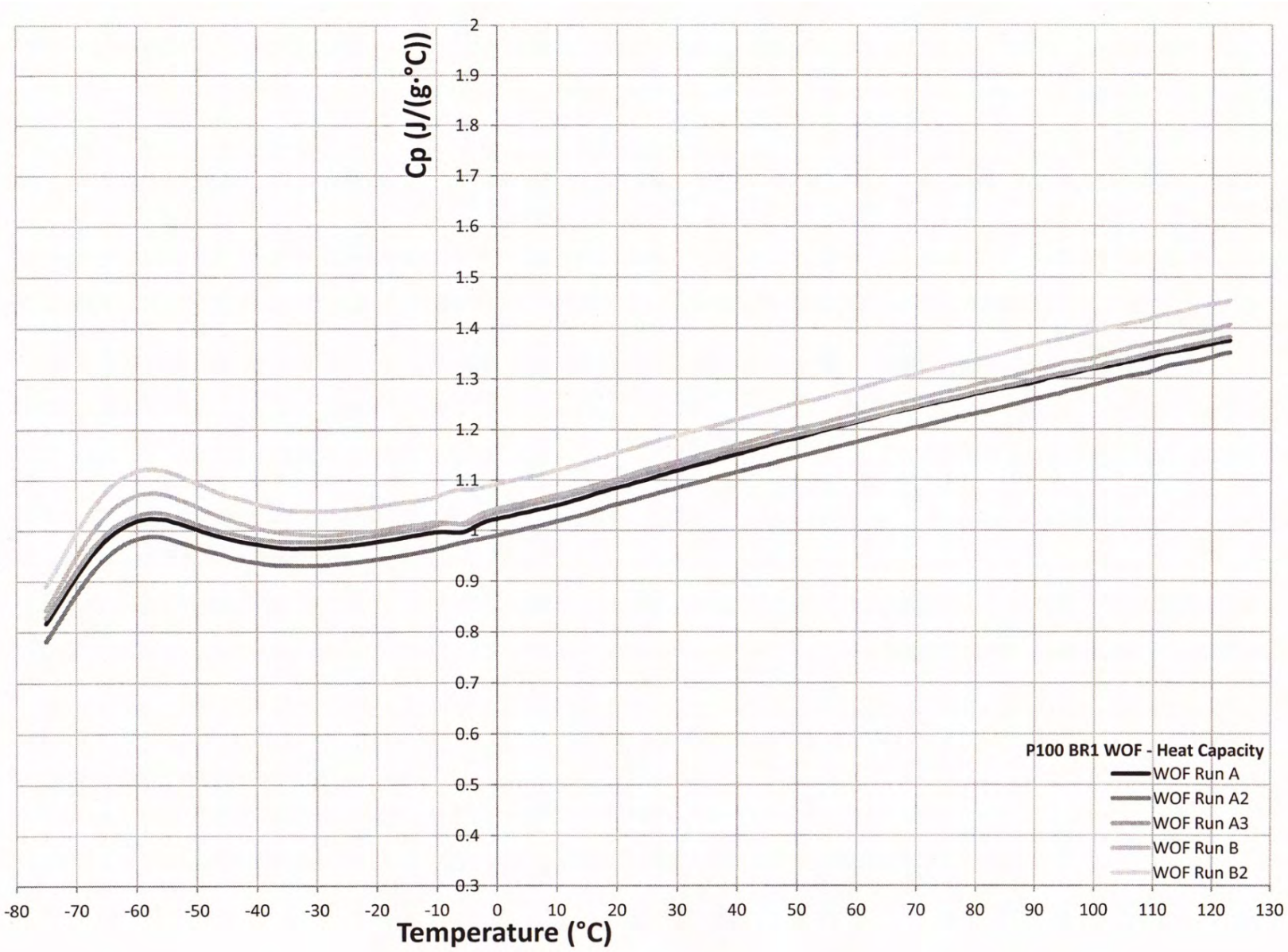


Figure HC15, Heat Capacity Curves for P100S BR1 WOF

7.0 APPENDIX E: DIFFUSIVITY

7.1 Section 1: YSH50A Diffusivity

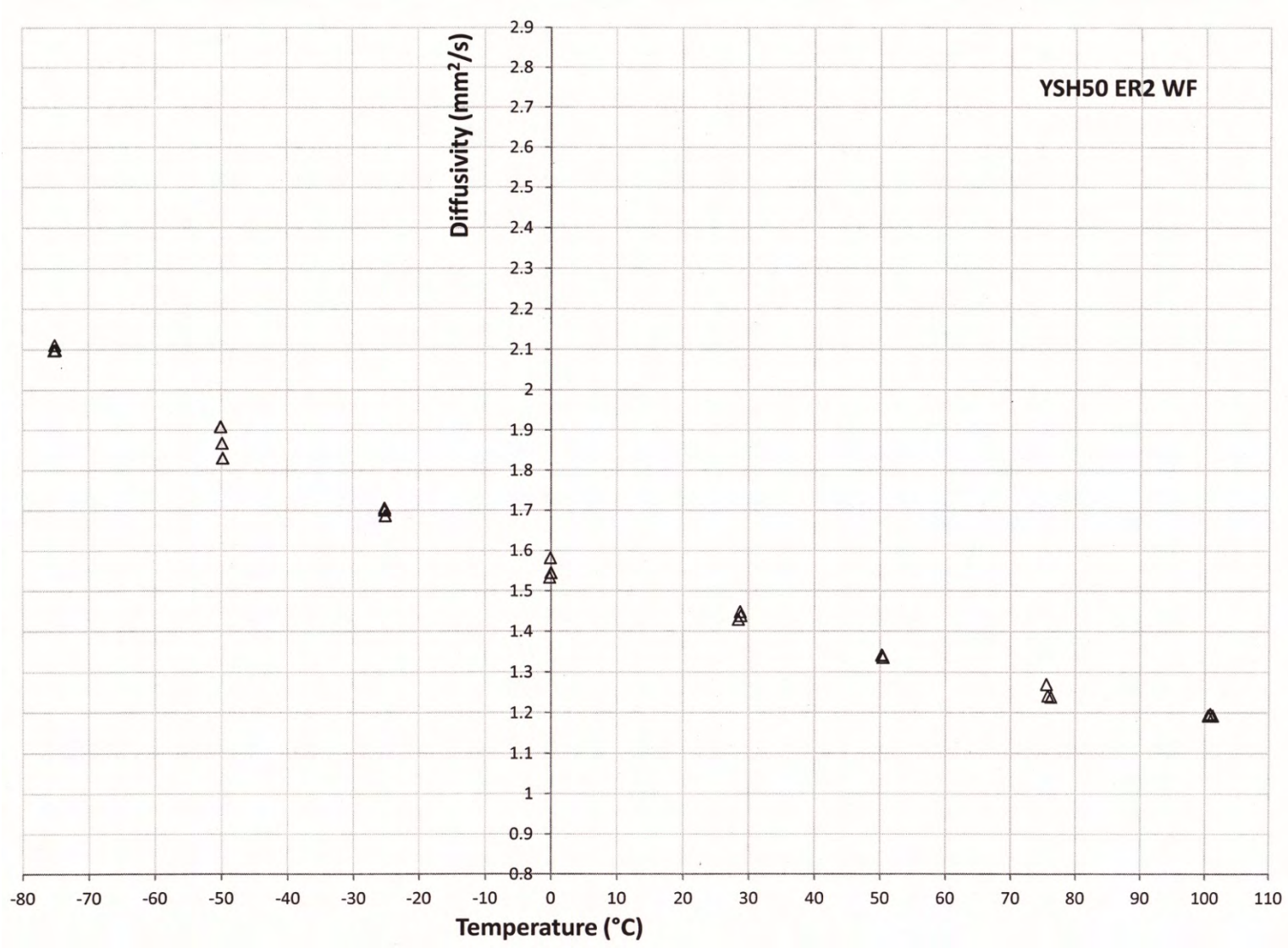


Figure D1, YSH50A ER2 WF Diffusivity

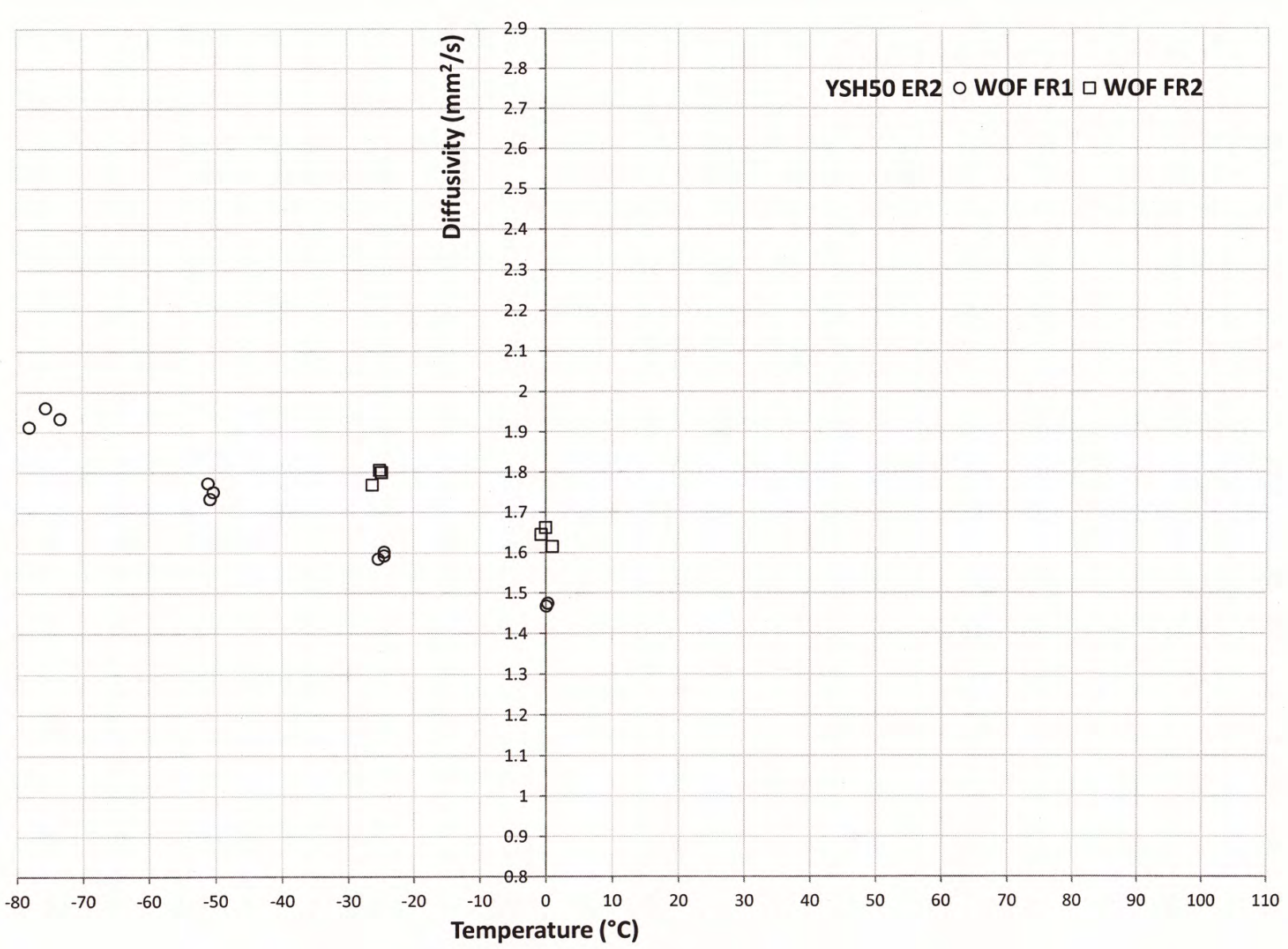


Figure D2, YSH50A ER2 WOF Diffusivity

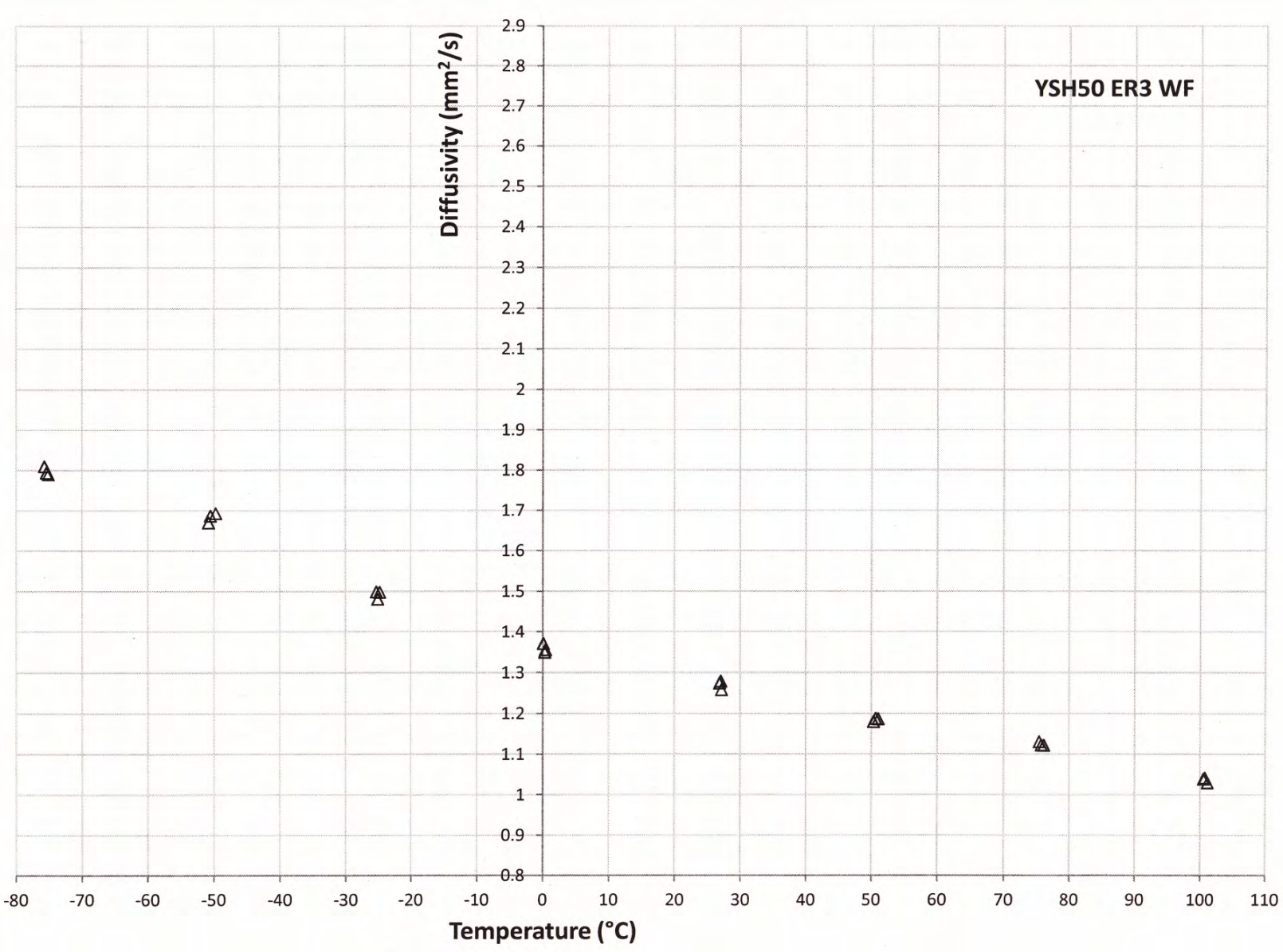


Figure D3, YSH50A ER3 WF Diffusivity

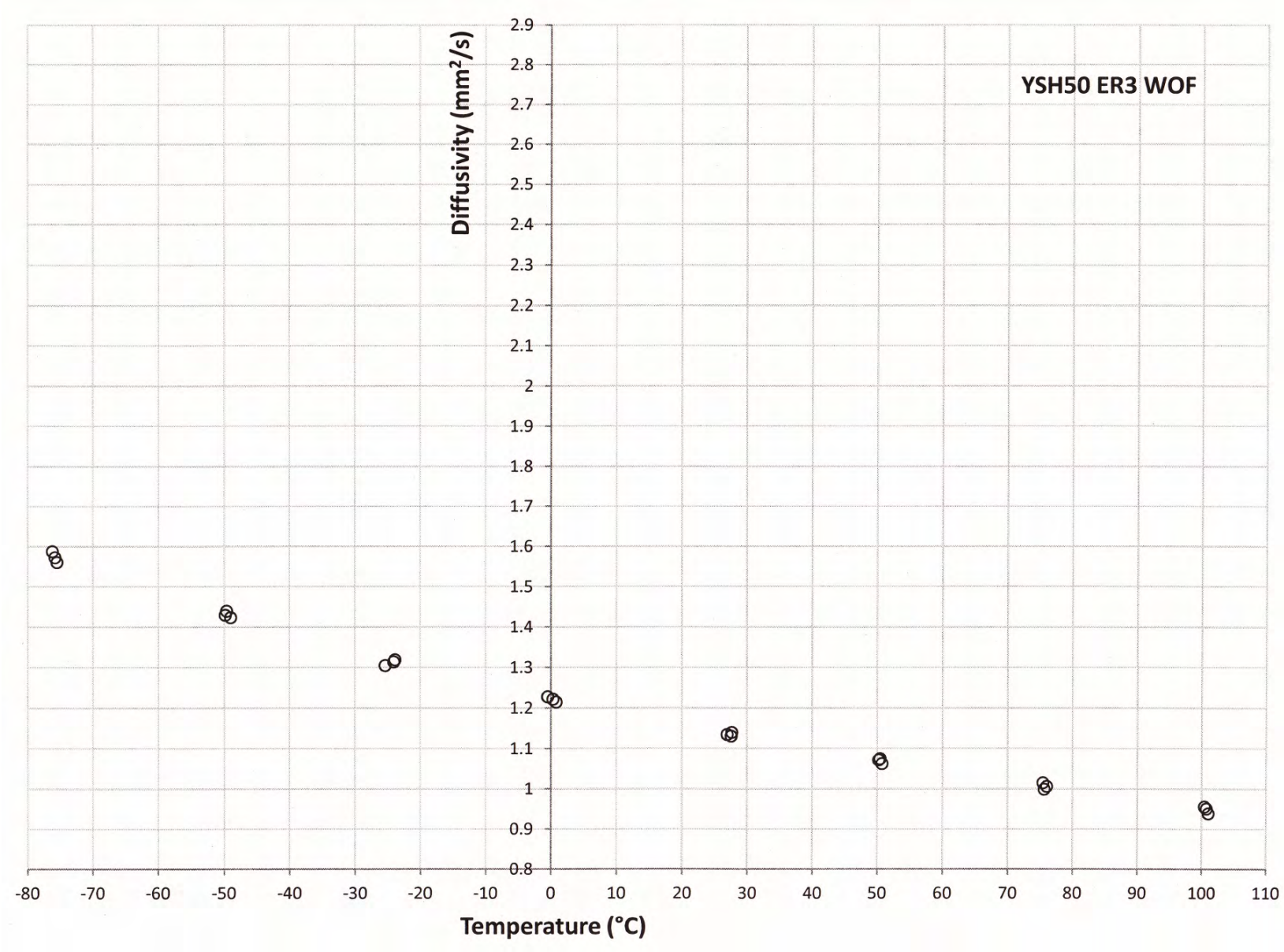


Figure D4, YSH50A ER3 WOF Diffusivity

7.2 Section 2: YS80A Diffusivity

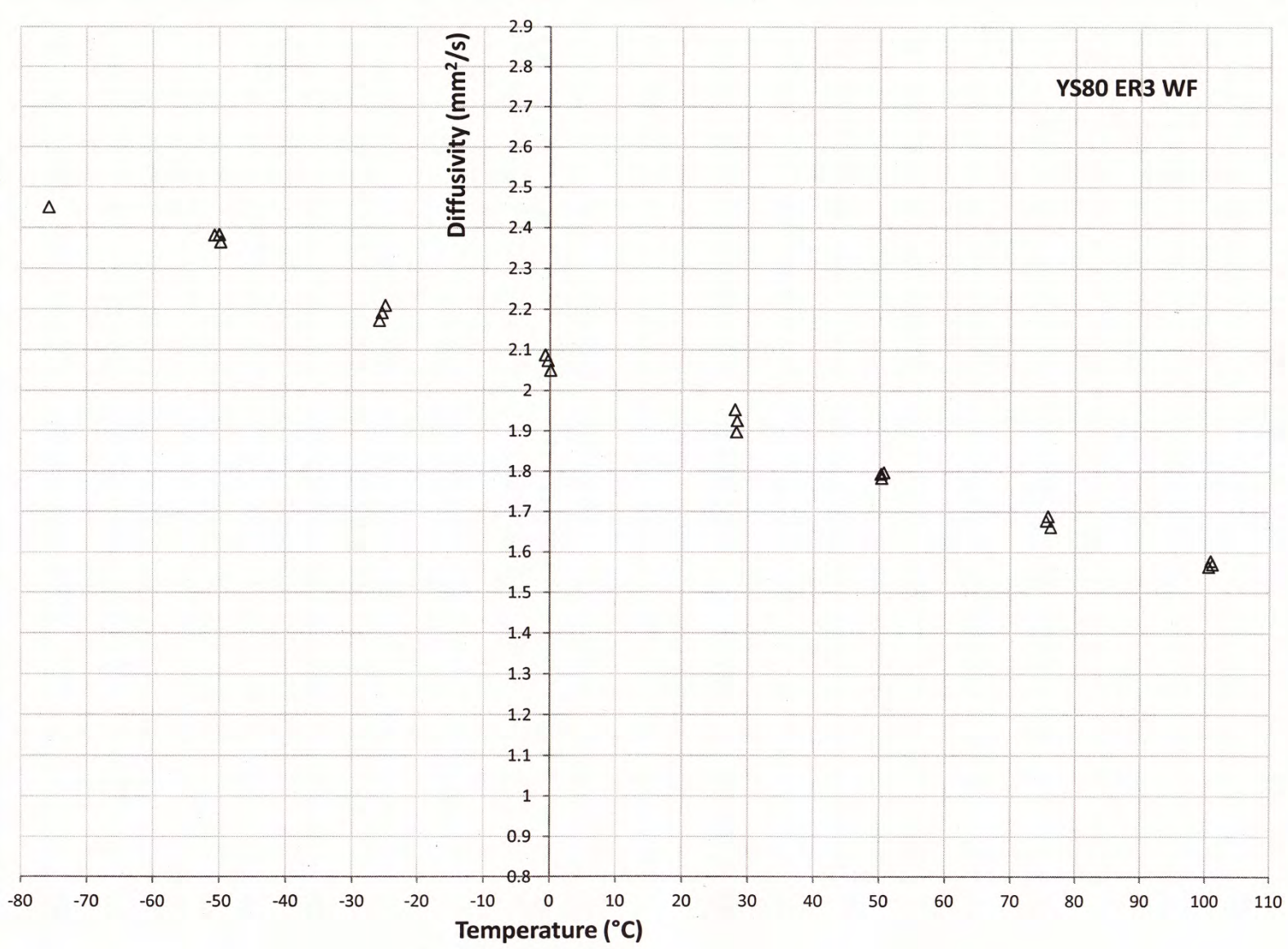


Figure D5, YS80A ER3 WF Diffusivity

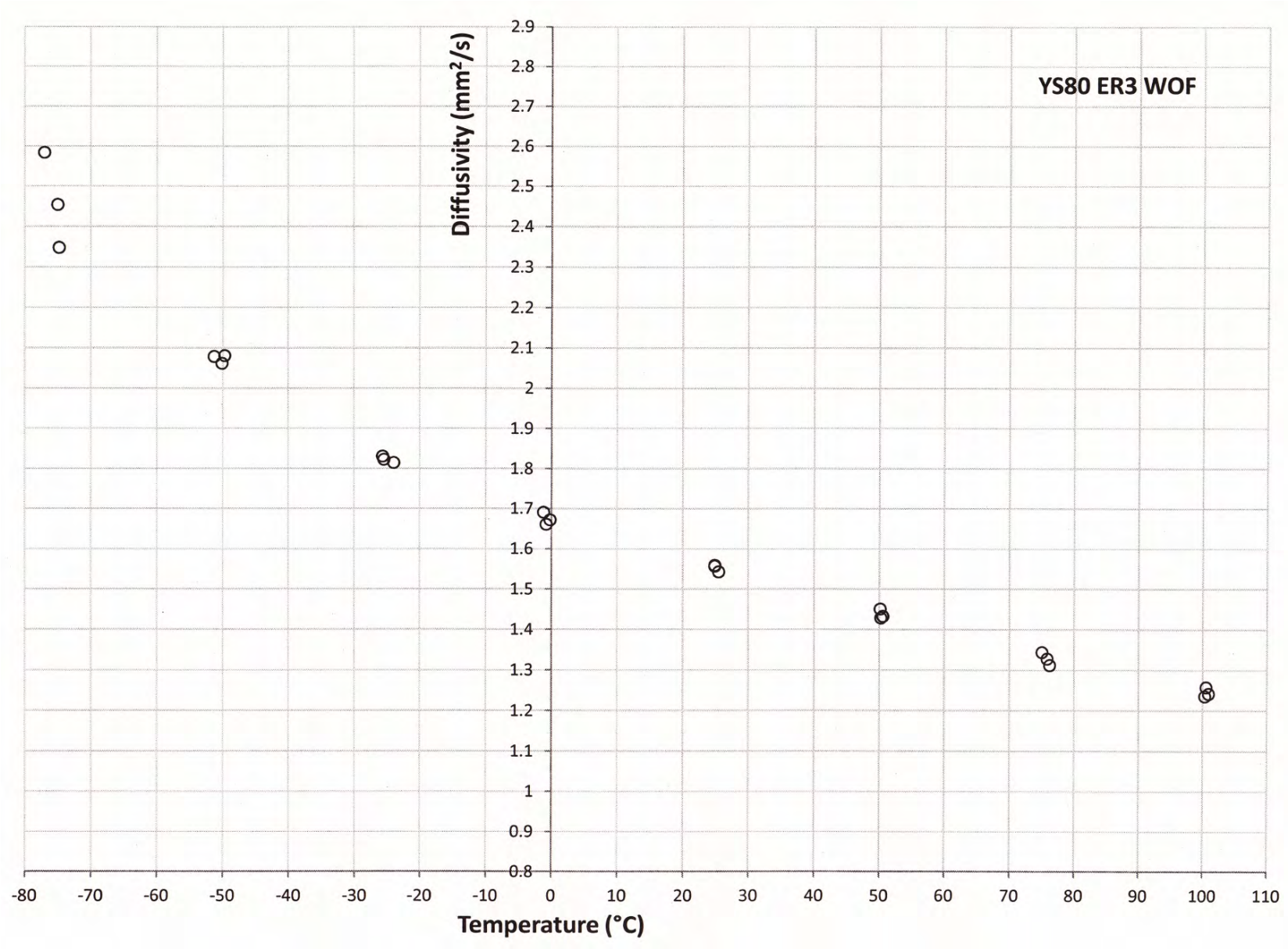


Figure D6, YS80A ER3 WOF Diffusivity

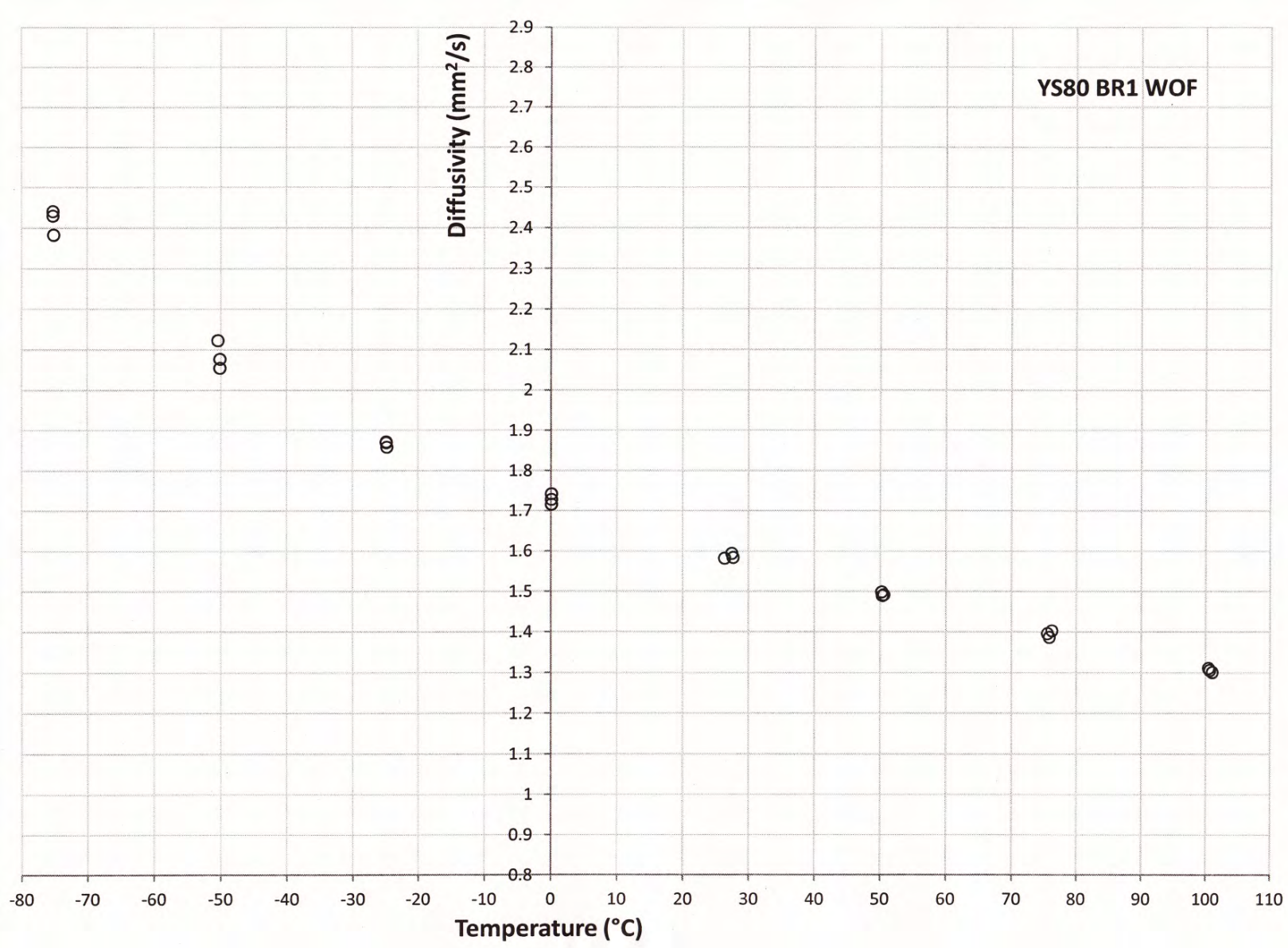


Figure D7, YS80A BR1 WOF Diffusivity

7.3 Section 3: P100S Diffusivity

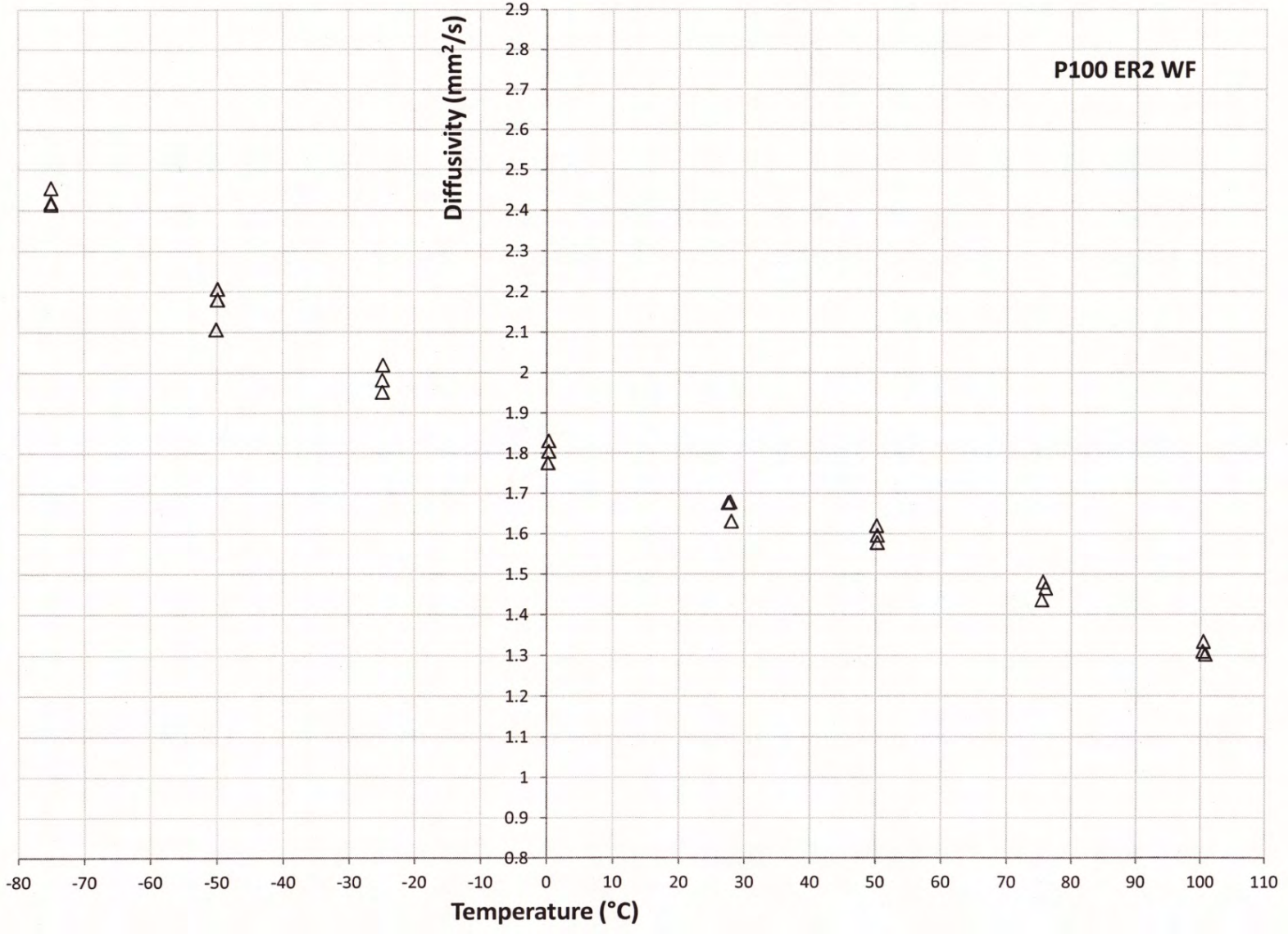


Figure D8, P100S ER2 WF Diffusivity

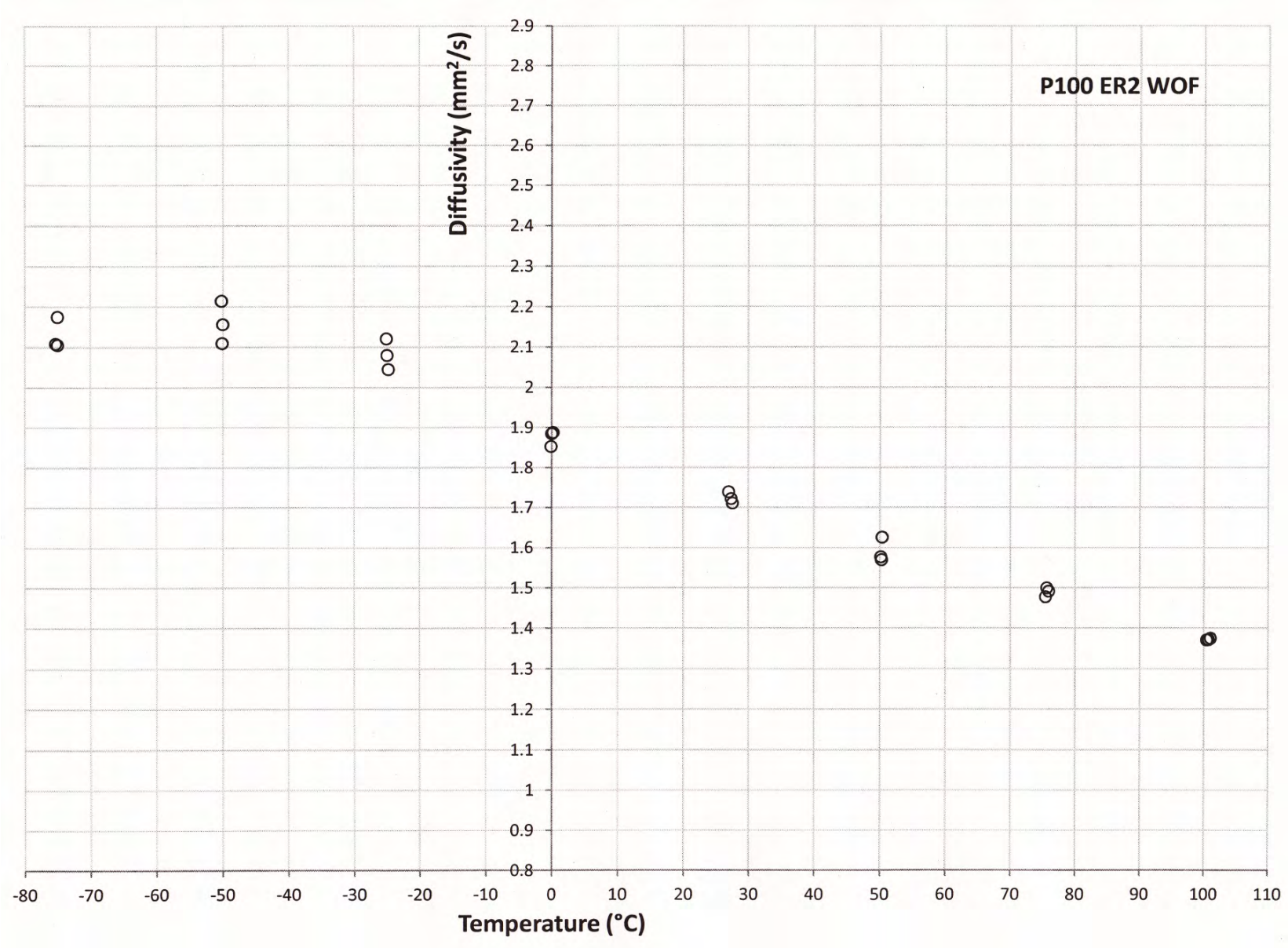


Figure D9, P100S ER2 WOF Diffusivity

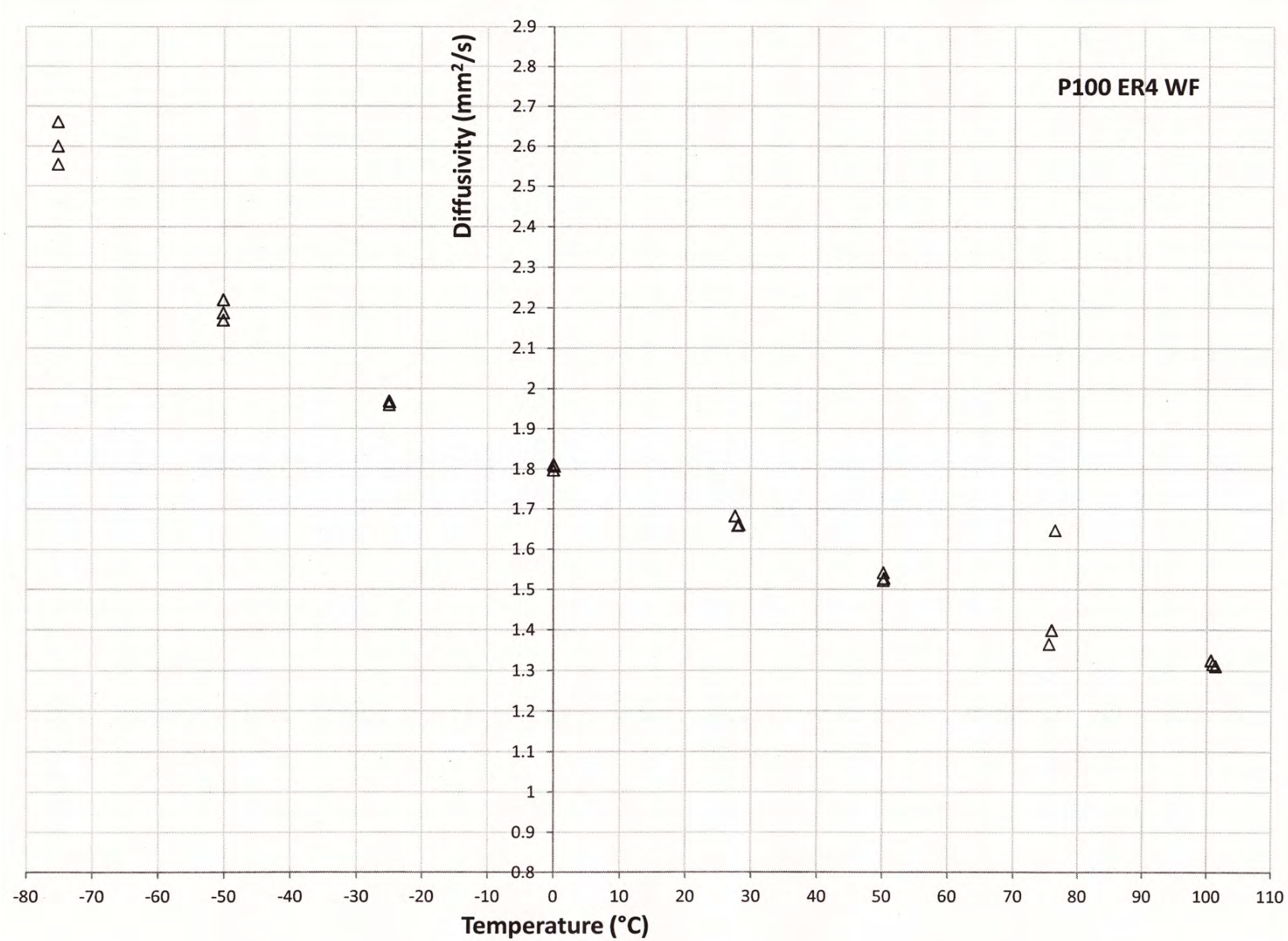


Figure D10, P100S ER4 WF Diffusivity

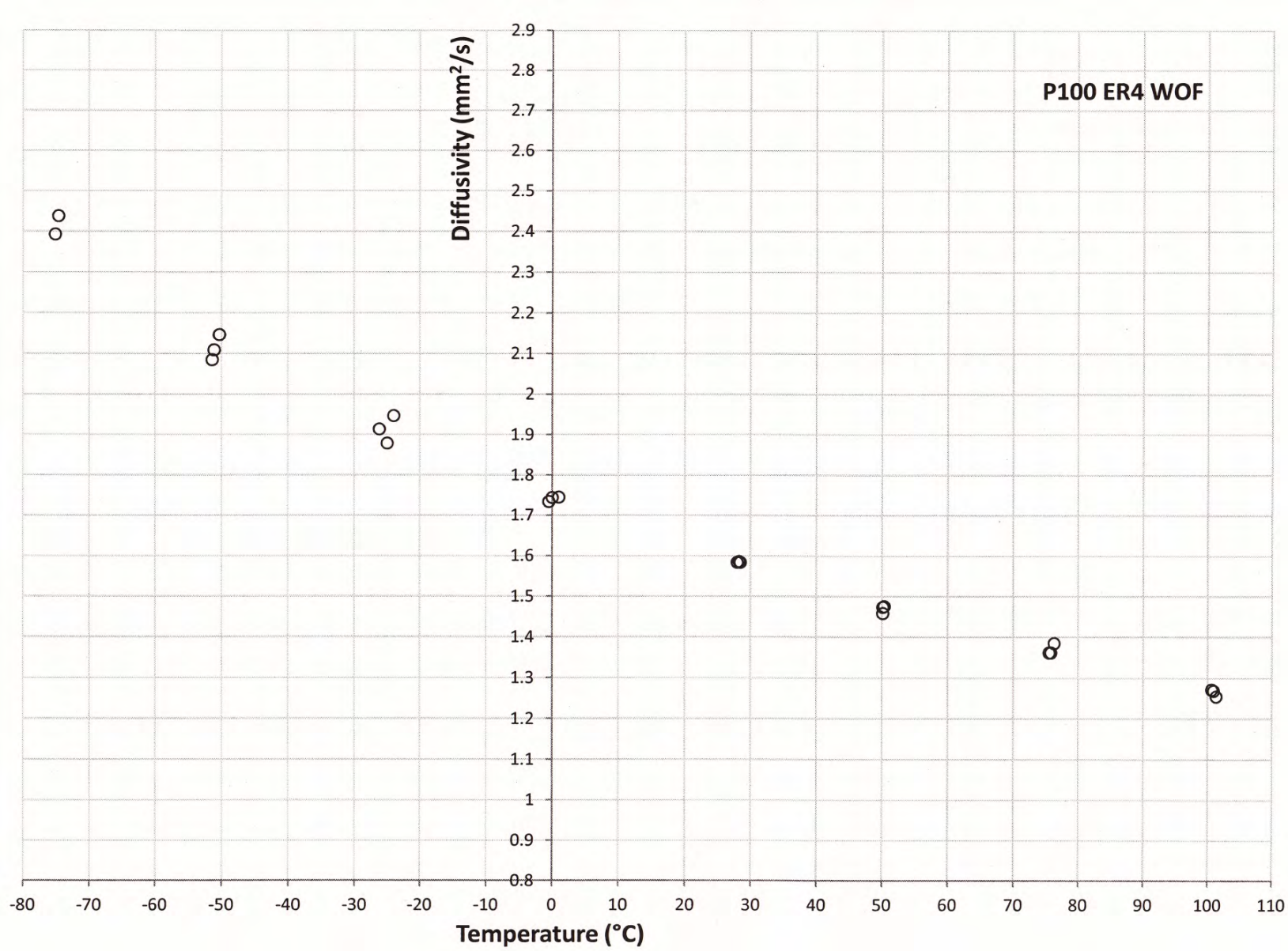


Figure D11, P100S ER4 WOF Diffusivity

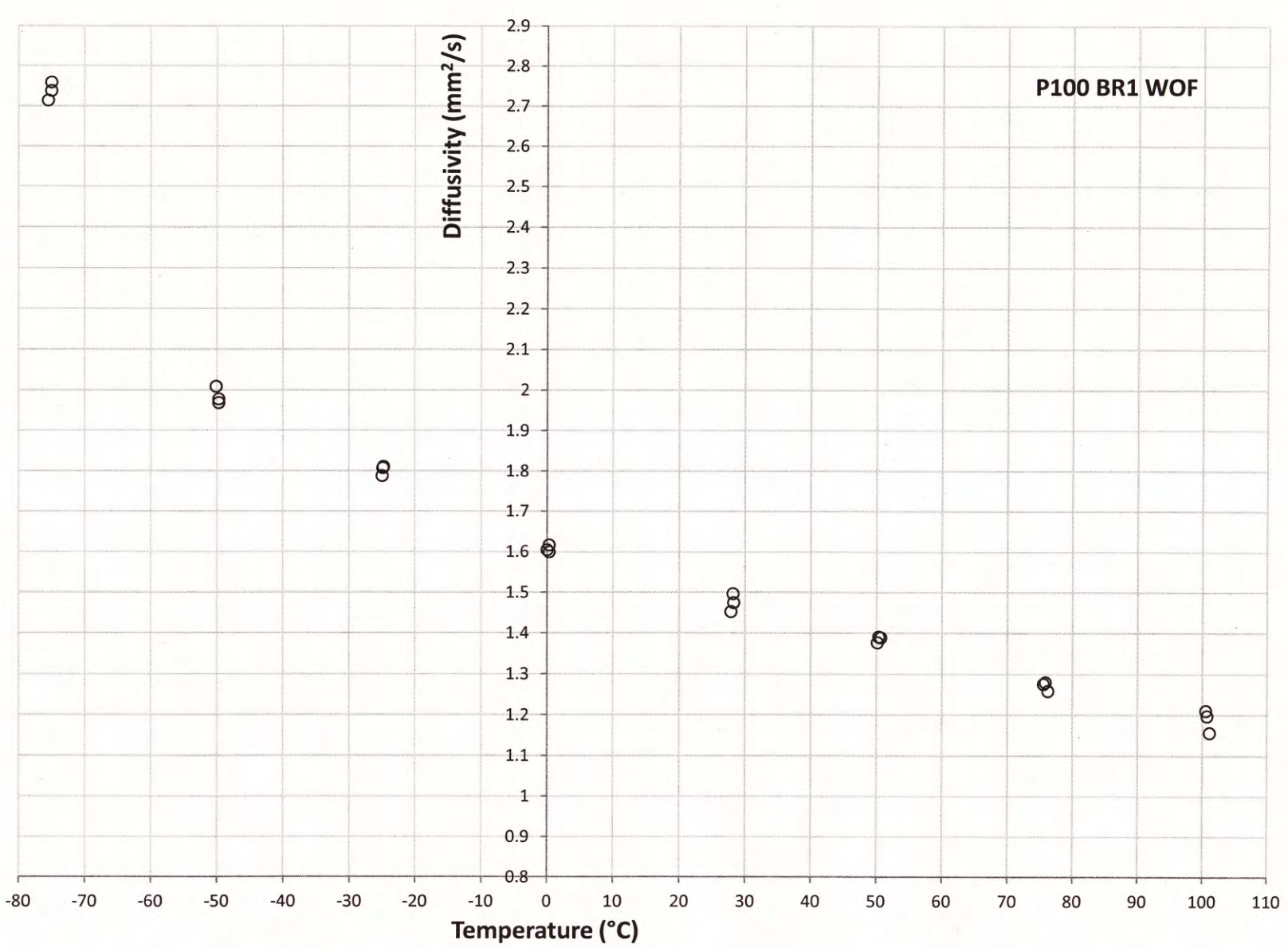


Figure D12, P100S BR1 WOF Diffusivity

8.0 APPENDIX F: CONDUCTIVITY

8.1 Section 1: YSH50A Conductivity

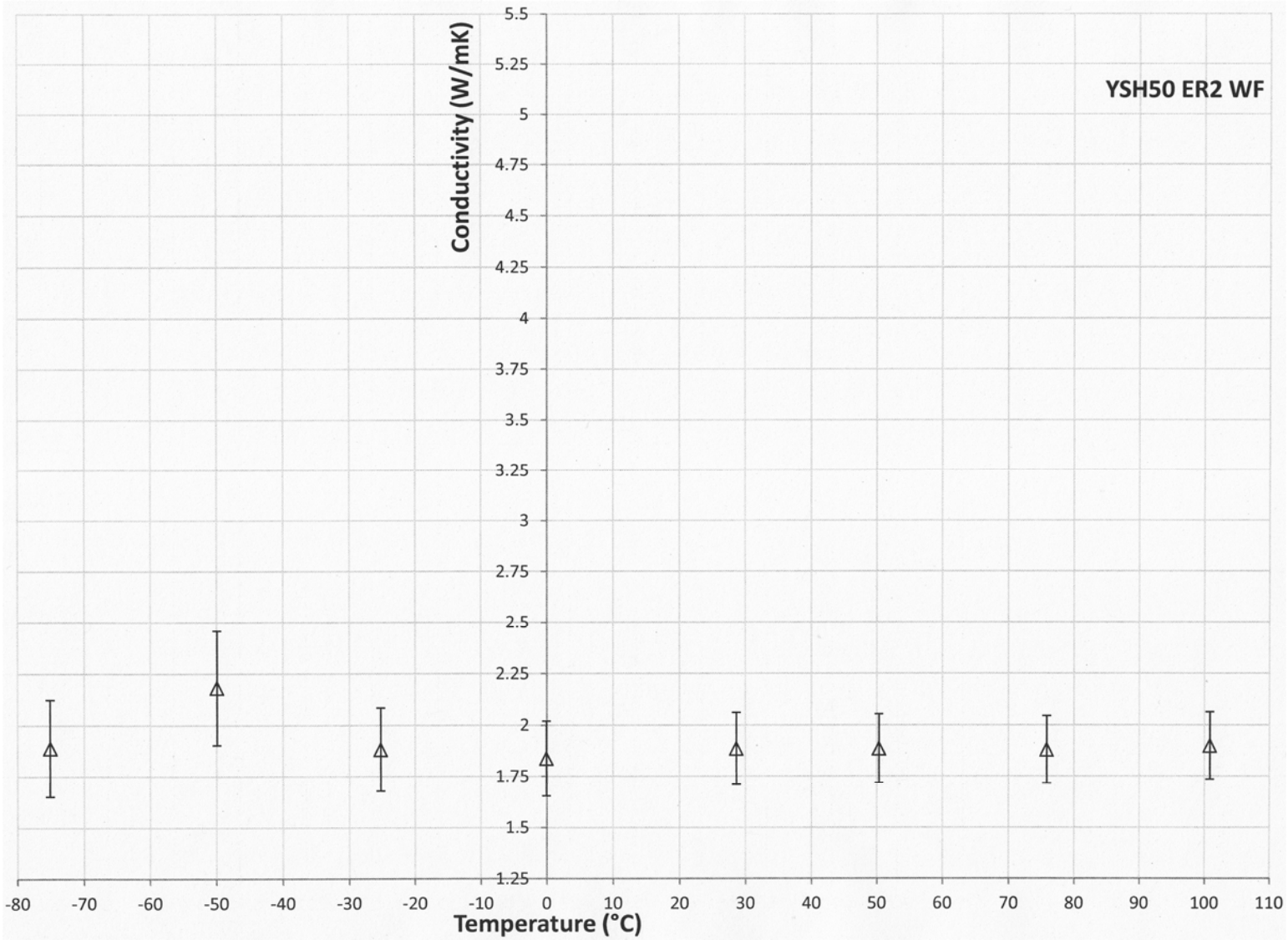


Figure C1, YSH50A ER2 WF Conductivity

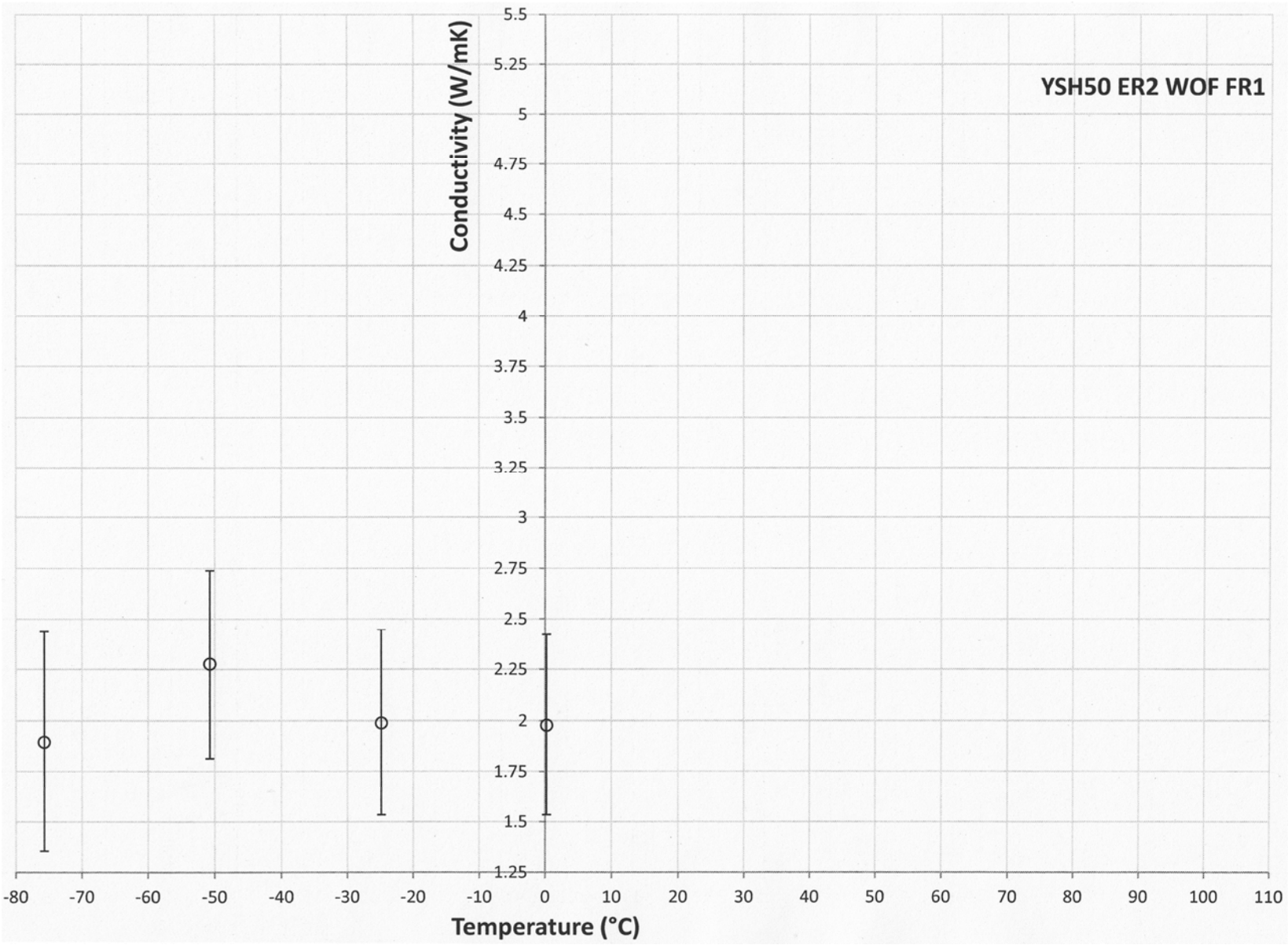


Figure C2, YSH50A ER2 FR1 WOF Conductivity

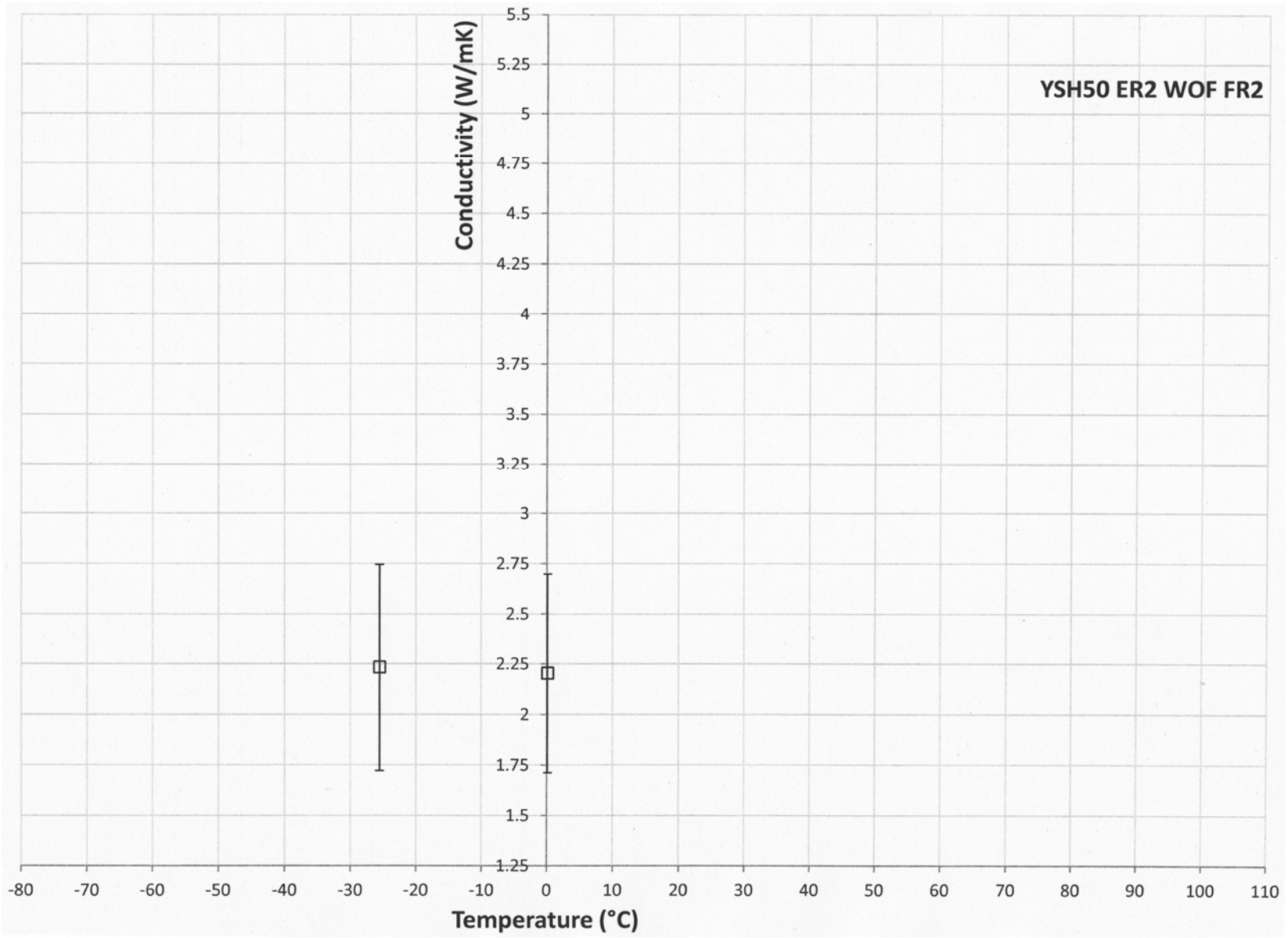


Figure C3, YSH50A ER2 FR2 WOF Conductivity

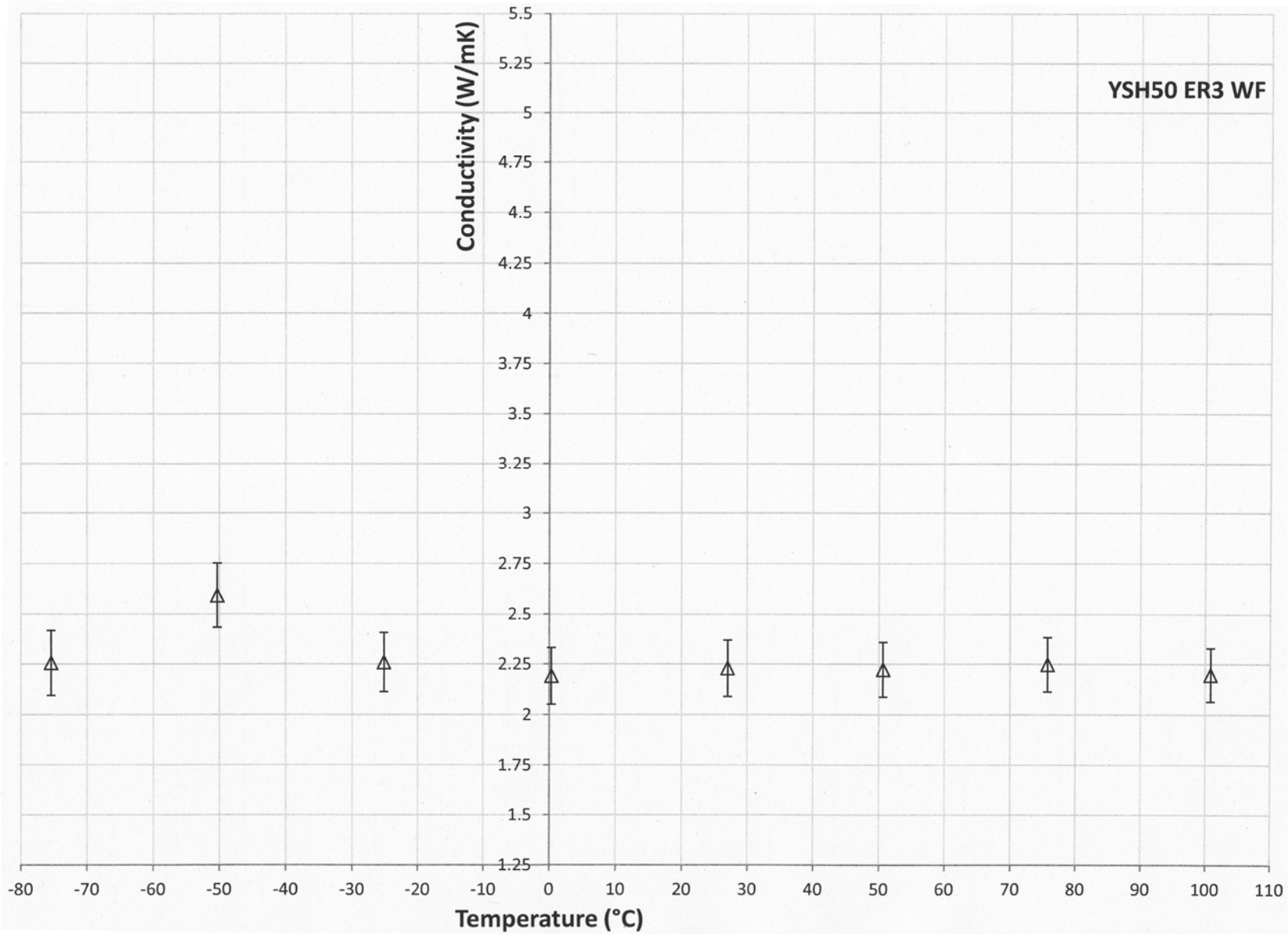


Figure C4, YSH50A ER3 WF Conductivity

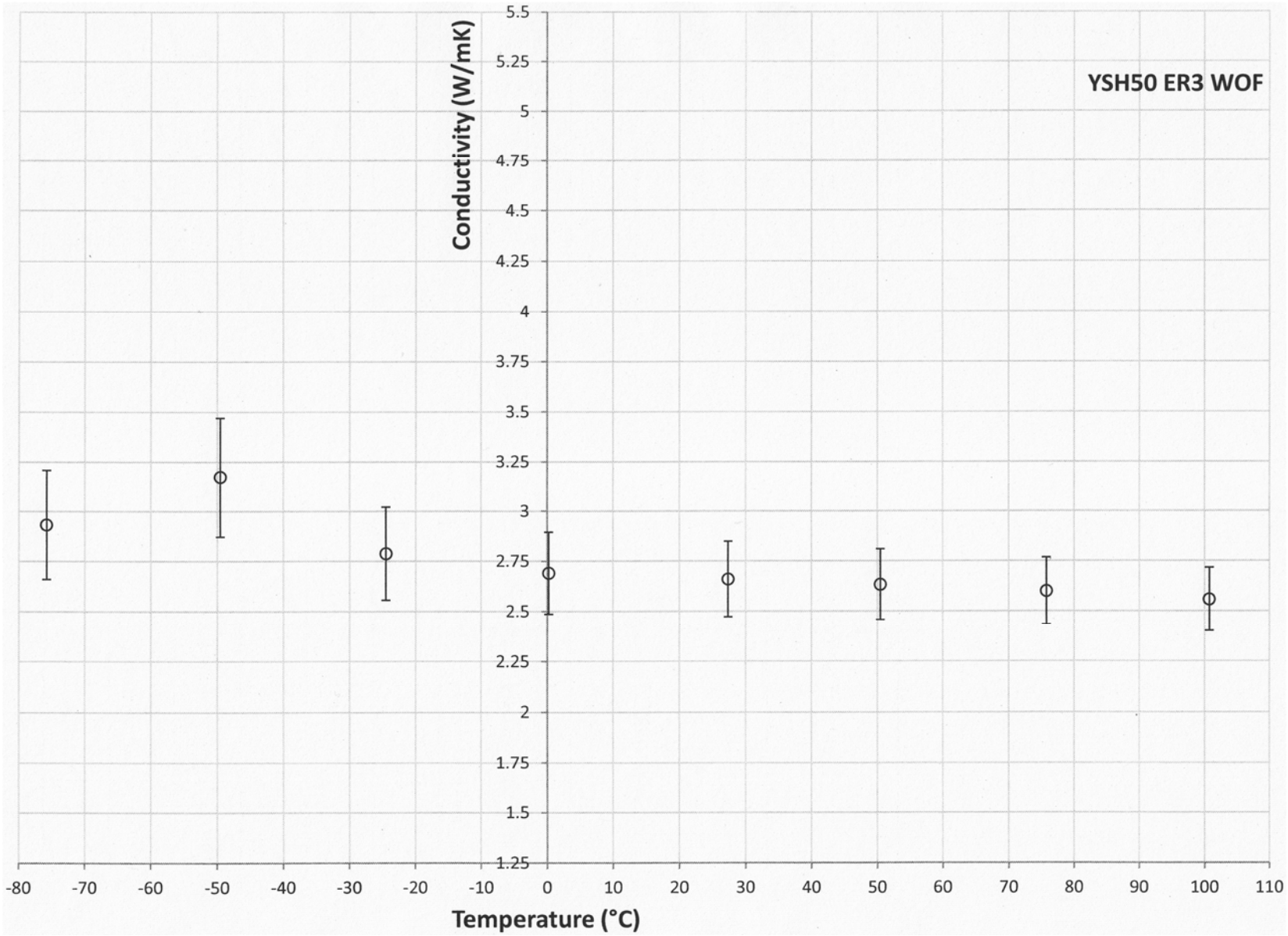


Figure C5, YSH50A ER3 WOF Conductivity

8.2 Section 2: YS80A Conductivity

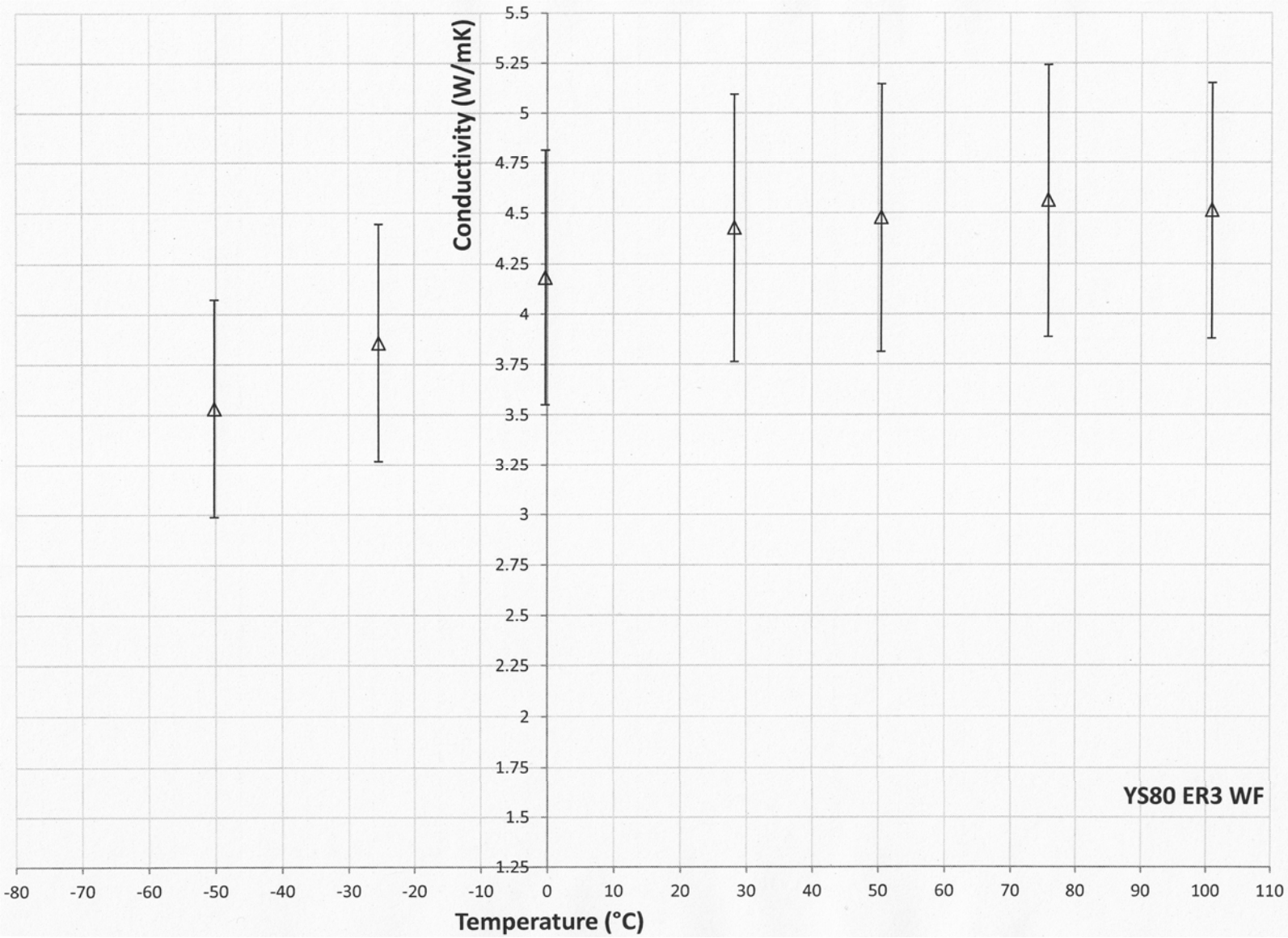


Figure C6, YS80A ER3 WF Conductivity ReRun

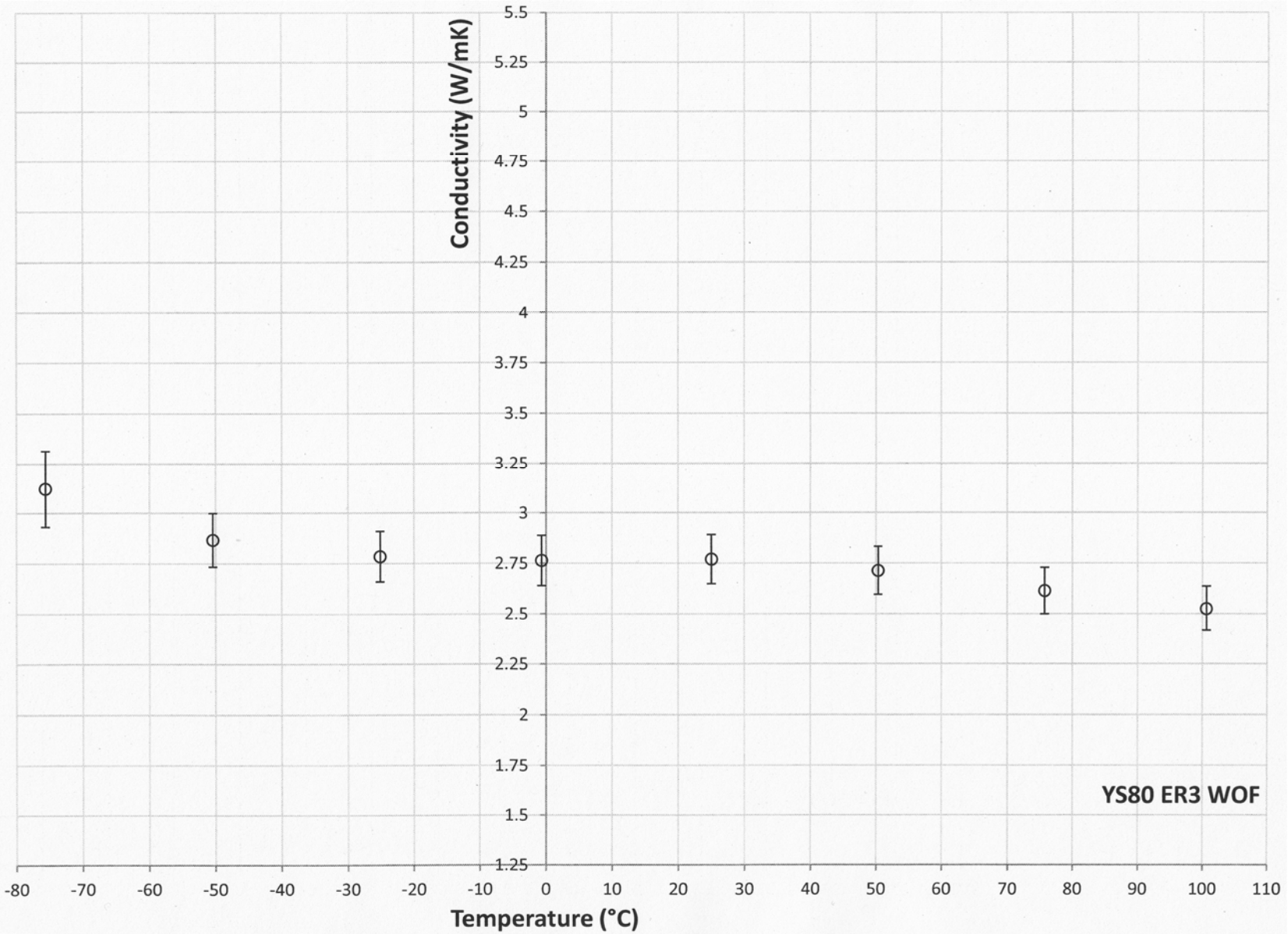


Figure C7, YS80A ER3 WOF Conductivity ReRun

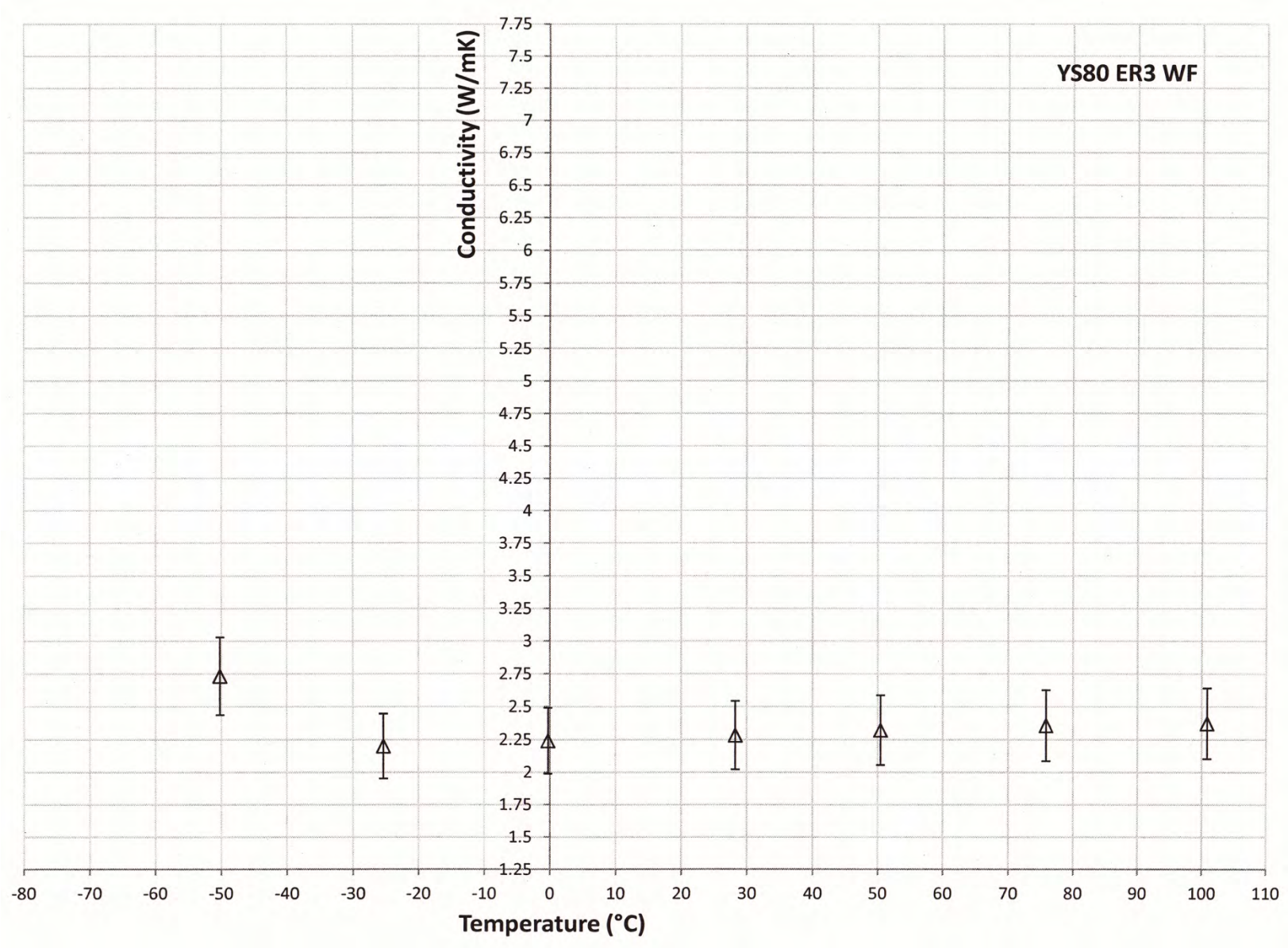


Figure C8, YS80A ER3 WF Conductivity Initial

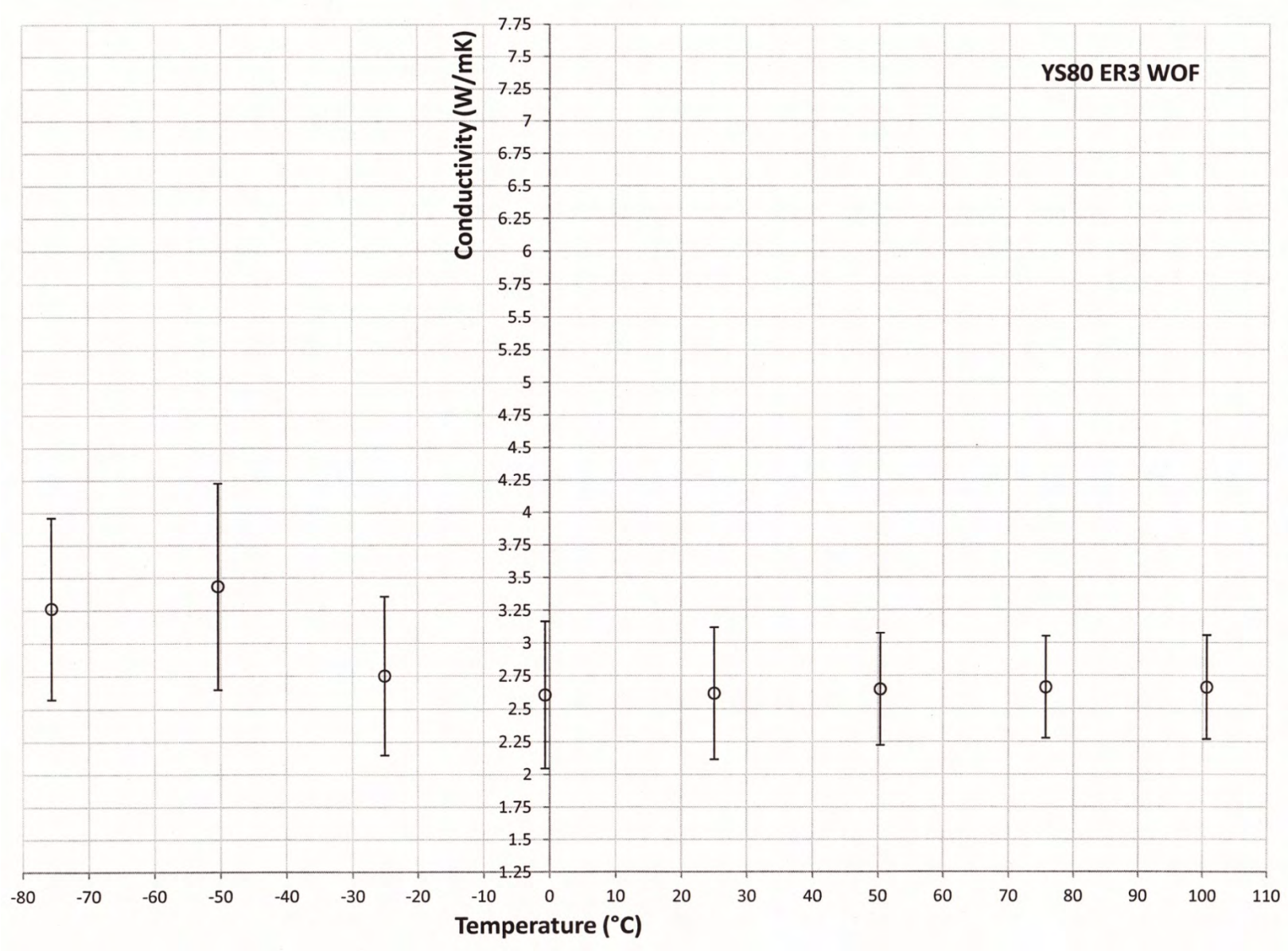


Figure C9, YS80A ER3 WOF Conductivity Initial

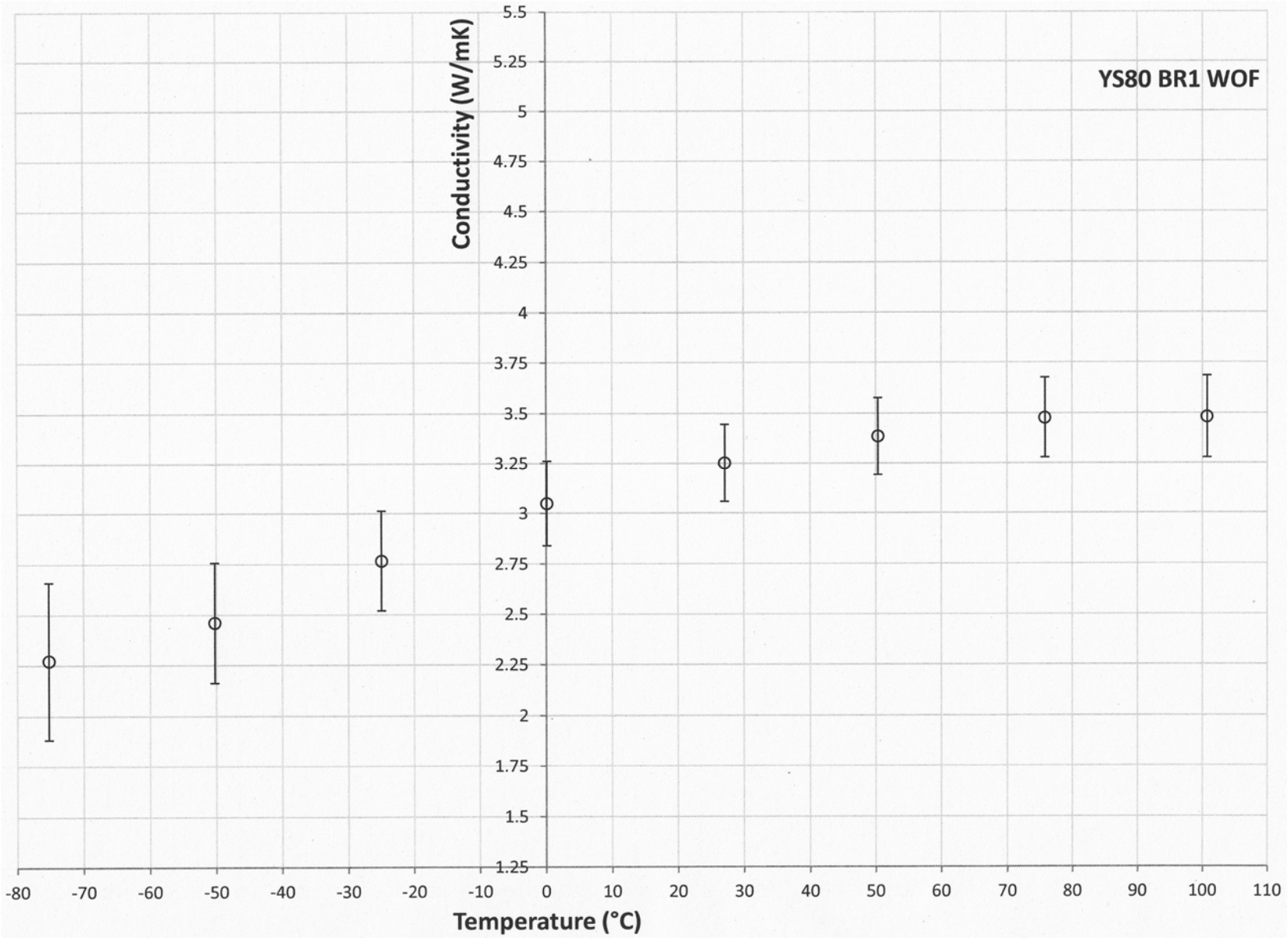


Figure C10, YS80A BR1 WOF Conductivity ReRun

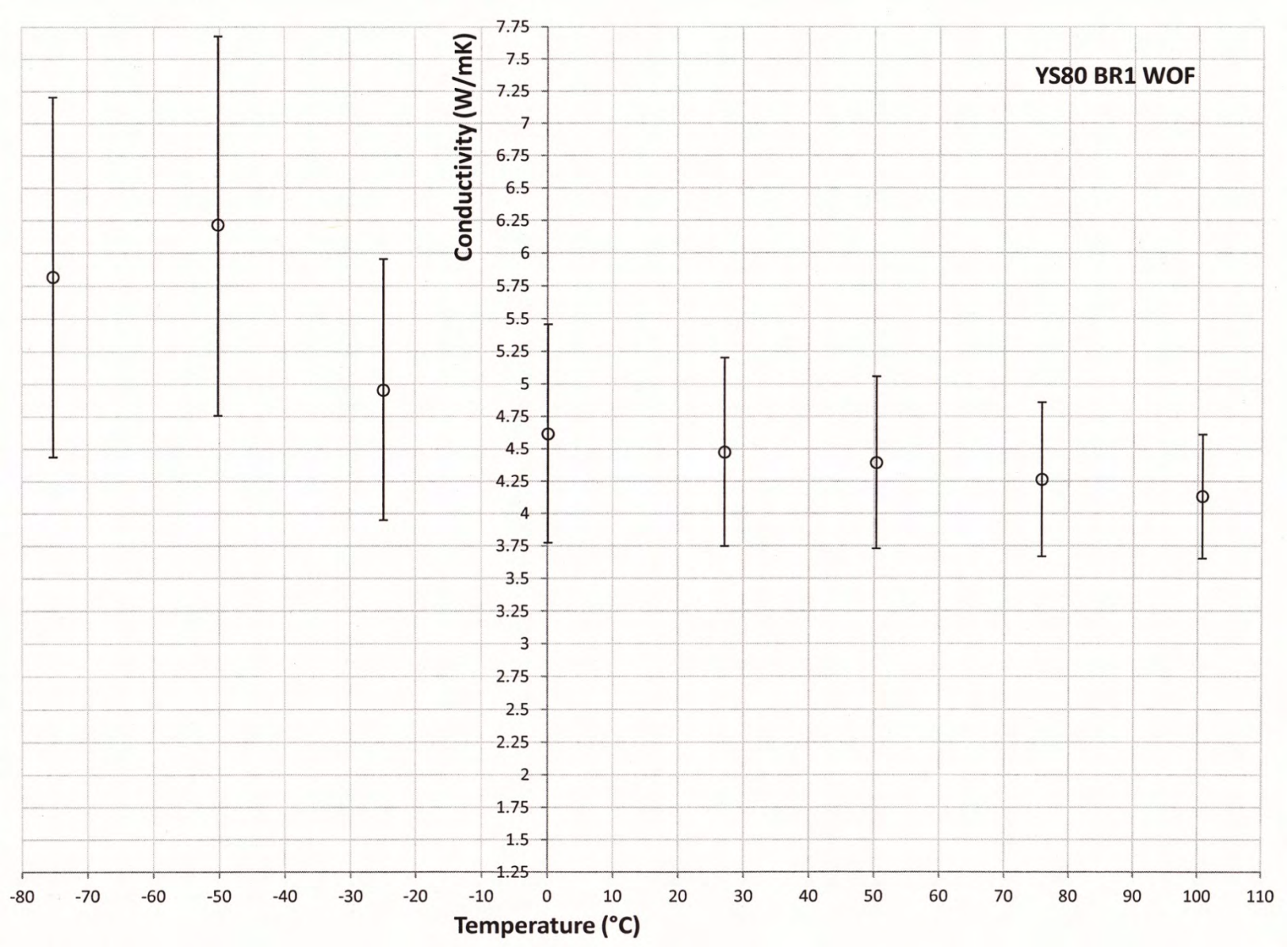


Figure C11, YS80A BR1 WOF Conductivity Initial

8.3 Section 3: P100S Conductivity

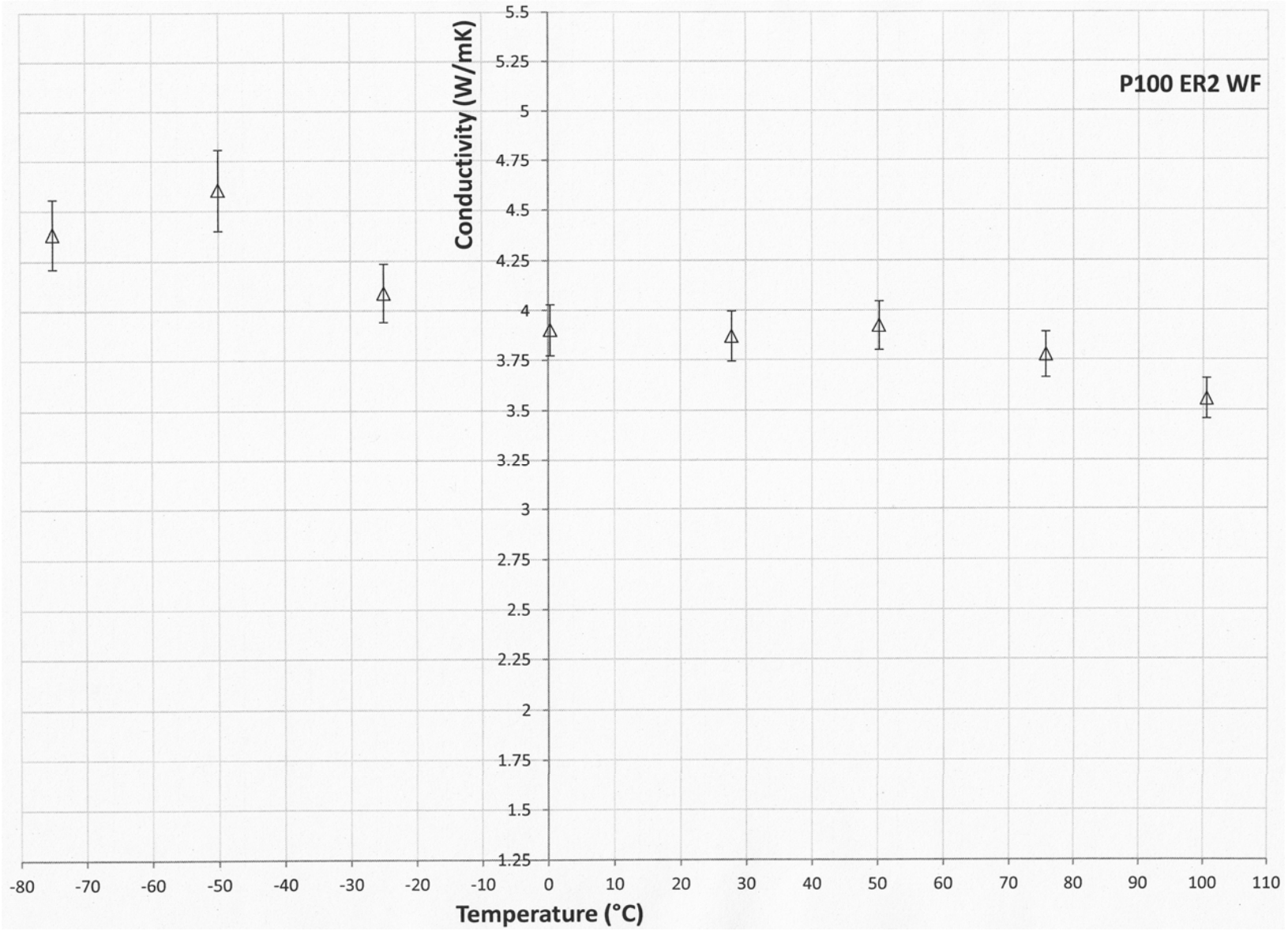


Figure C12, P100S ER2 WF Conductivity

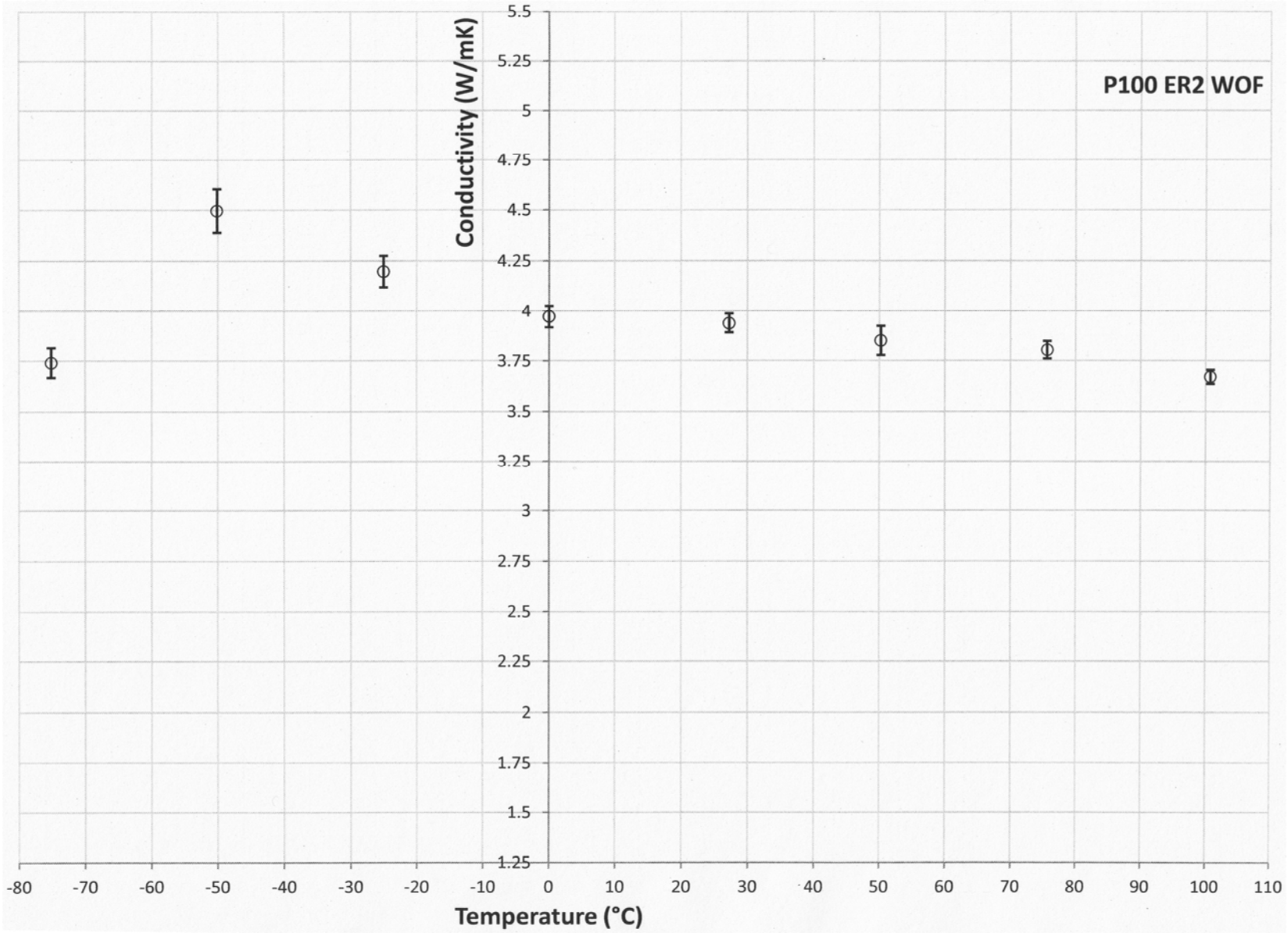


Figure C13, P100S ER2 WOF Conductivity

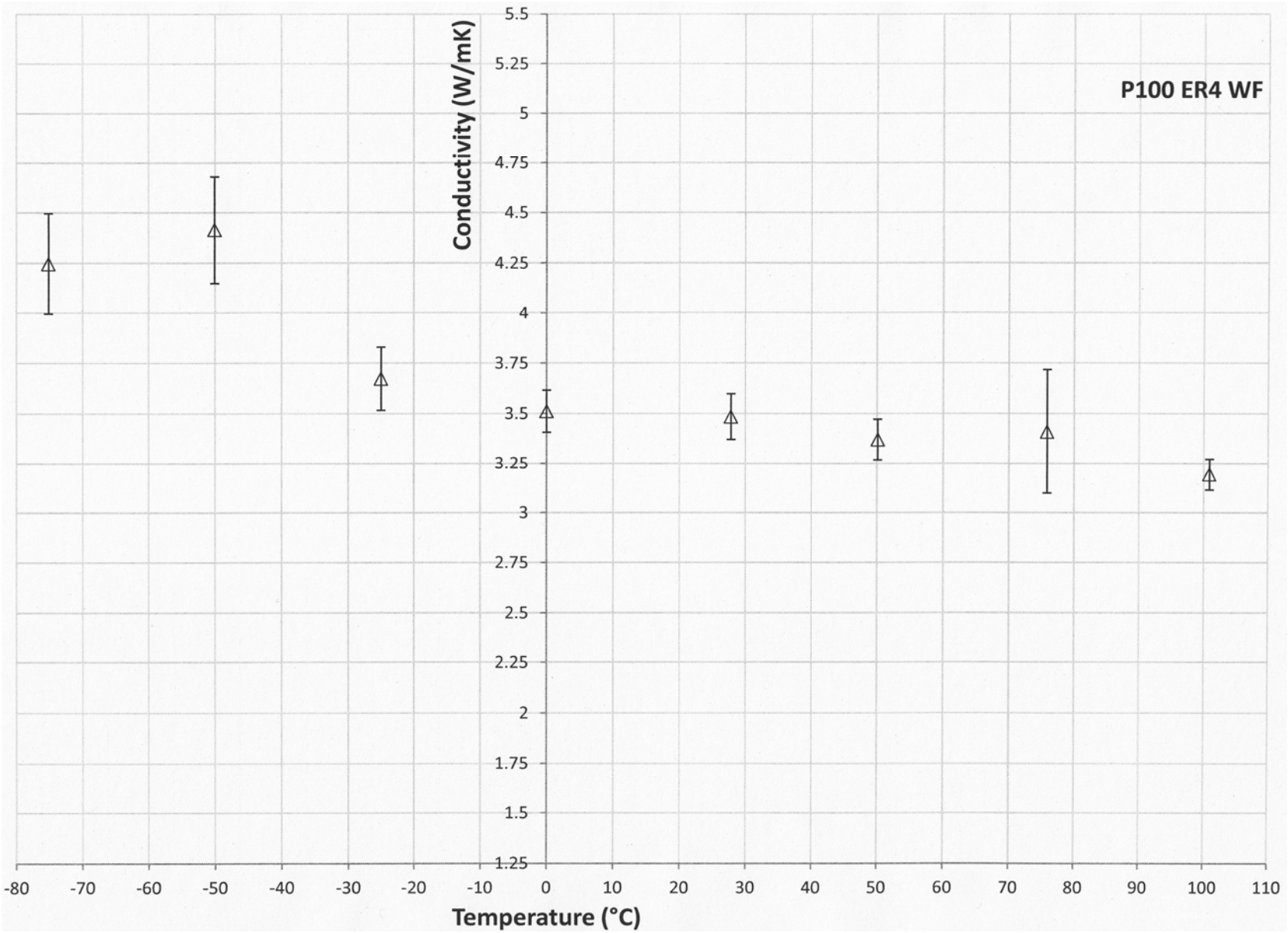


Figure C14, P100S ER4 WF Conductivity

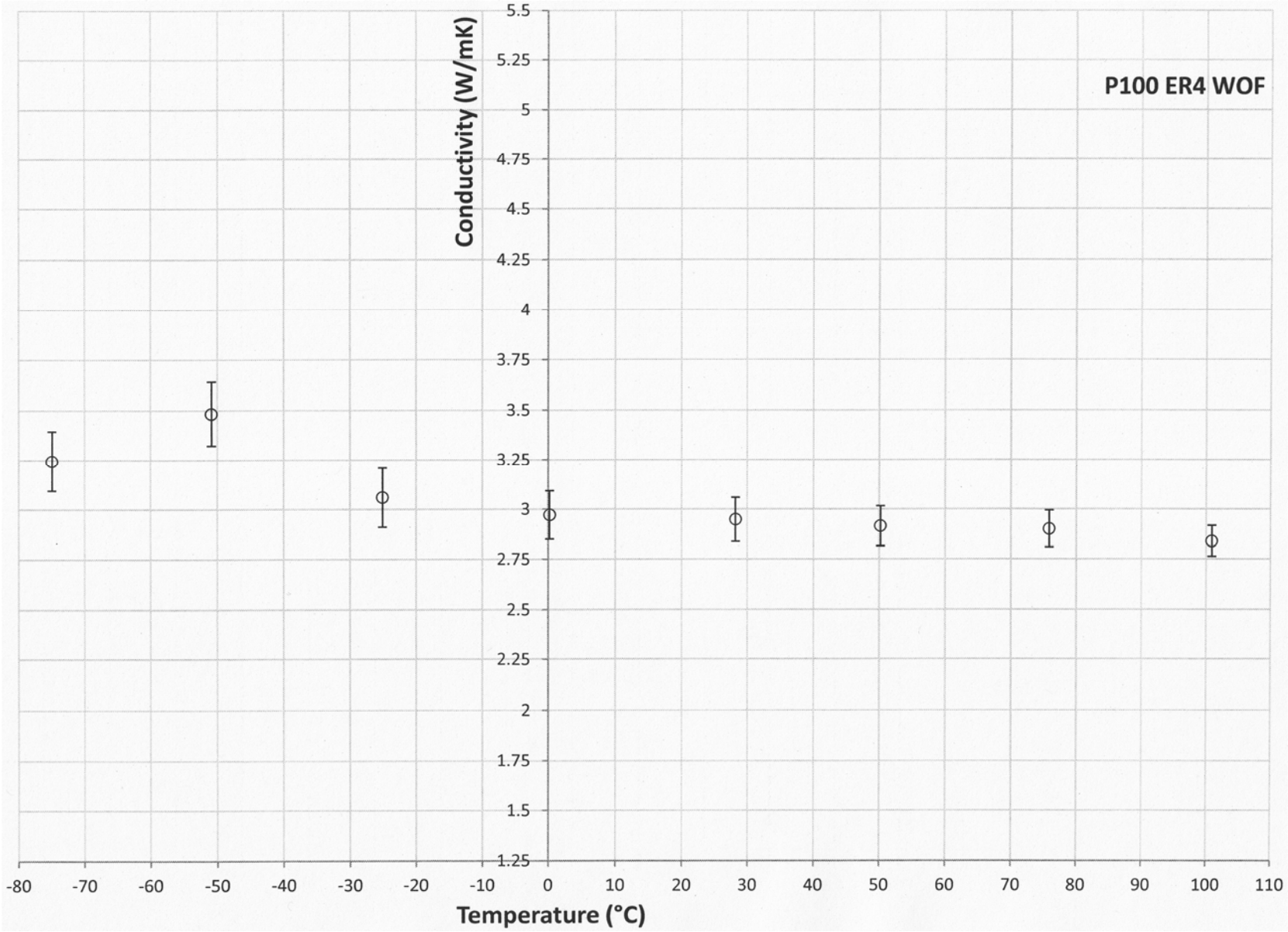


Figure C15, P100S ER4 WOF Conductivity

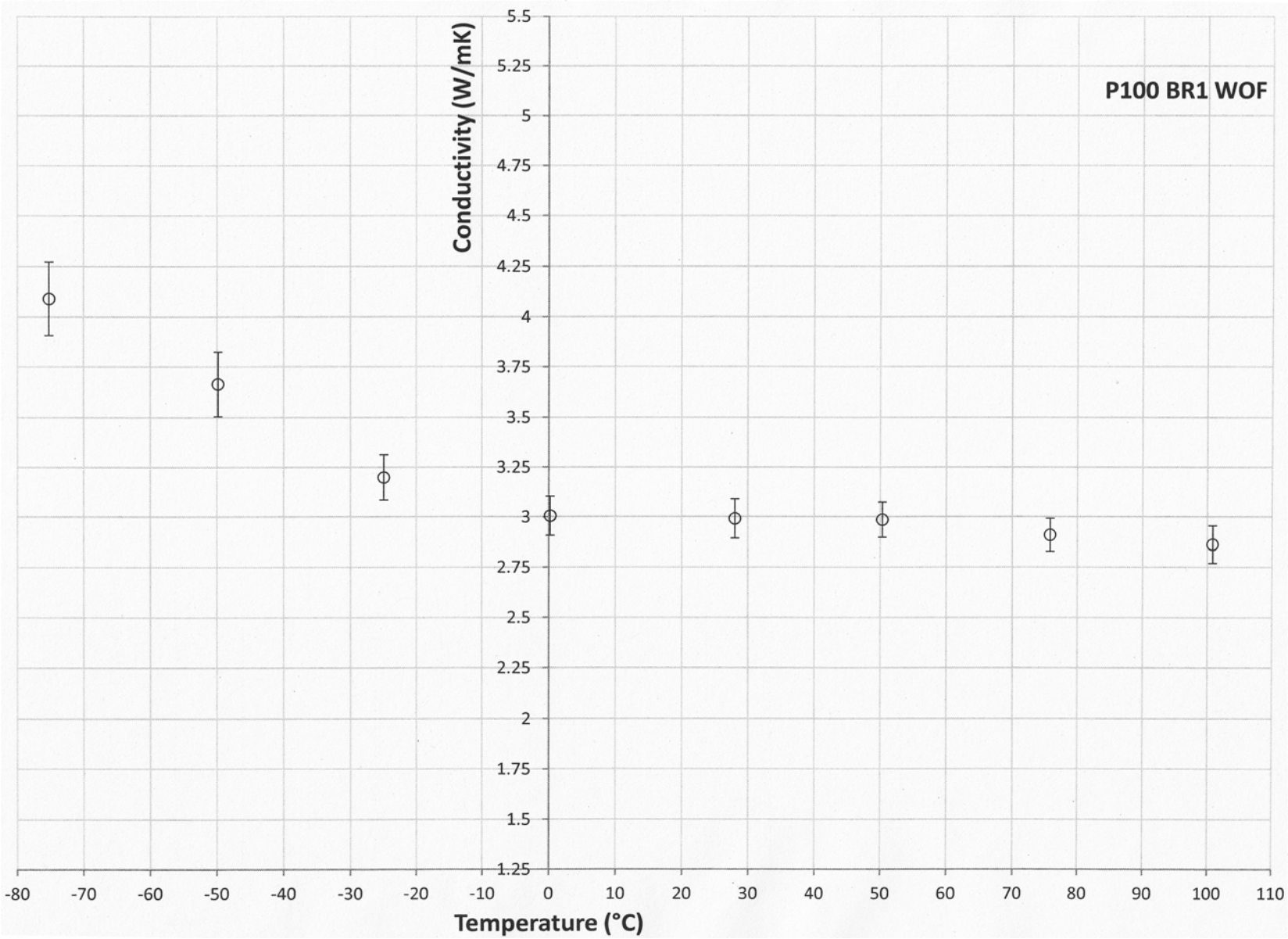


Figure C16, P100S BR1 WOF Conductivity

9.0 APPENDIX G: ABREVIATIONS

Abbreviation	Meaning
STD	Standard Deviation
WF	With Fins
WOF	Without Fins
MCDS	Modulated Differential Scanning Calorimetry
°C	Degrees Celsius
J	Joules
g	Grams
N_2	Nitrogen
C_p	Heat Capacity
A	Specimen A
A1	First Run of Specimen A
A2	Second Run of Specimen A
B	Specimen B
B1	First Run of Specimen B
B2	Second Run of Specimen B
gms	Grams
K	Kelvin
k	Conductivity
W	Watts
m	Meters
V_F	Fiber Volume
sccm	Standard Cubic Centimeters
TBE	Tote Bundle Edge
psi	Pounds per square inch
°F	Degrees Fahrenheit
nm	Nanometers
H_2	Hydrogen
MPa	Megapascal
Lbf	Pound-force
FG	Fin Growth
D	Diffusivity
BCF	Bulk Composite Fabrication
OM	Optical Microscopy
MWCVD	Microwave Plasma Chemical Vapor Deposition